US007173576B2

(12) United States Patent
O'Neill, Jr. et al.

(10) Patent No.: US 7,173,576 B2
(45) Date of Patent: Feb. 6, 2007

(54) HANDSET QUADRIFILAR HELICAL ANTENNA MECHANICAL STRUCTURES

(75) Inventors: **Gregory A. O'Neill, Jr.**, Rockledge, FL (US); **Young-Min Jo**, Viera, FL (US); **Paul A. Tornatta, Jr.**, Melbourne, FL (US); **John Charles Farrar**, Indialantic, FL (US); **Murray Fugate**, Coral Springs, FL (US); **Ki-Chul Kim**, Suwon (KR); **Joon-Wan Lee**, Seoul (KR)

(73) Assignee: **SkyCross, Inc.**, Viera, FL (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **11/130,035**

(22) Filed: **May 16, 2005**

(65) **Prior Publication Data**

US 2006/0022892 A1 Feb. 2, 2006

Related U.S. Application Data

(63) Continuation-in-part of application No. 10/998,301, filed on Nov. 26, 2004.

(60) Provisional application No. 60/592,011, filed on Jul. 28, 2004.

(51) **Int. Cl.**
H01Q 1/36 (2006.01)

(52) **U.S. Cl.** **343/895**; 343/702

(58) **Field of Classification Search** 343/795, 343/850, 796, 853, 702
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,896,113 A		4/1999	O'Neill, Jr.	
5,909,196 A		6/1999	O'Neill, Jr.	
5,920,292 A		7/1999	O'Neill, Jr.	
5,990,847 A		11/1999	Filipovic et al.	
6,052,089 A		4/2000	Eggleston	
6,054,966 A		4/2000	Haapala	
6,094,178 A		7/2000	Sanford	
6,212,413 B1		4/2001	Kiesi	
6,229,499 B1	*	5/2001	Licul et al.	343/895
6,232,929 B1		5/2001	Ermutlu et al.	
6,278,415 B1		8/2001	Matsuyoshi et al.	
6,288,686 B1		9/2001	Josypenko	
6,320,549 B1		11/2001	Nybeck et al.	
6,384,798 B1	*	5/2002	Barta et al.	343/895

(Continued)

OTHER PUBLICATIONS

Kilgus, C. C.; "Multielement Fractional Turn Helices"; IEEE Transactions on Antennas and Propagation; Jul. 1968; pp. 499-500.
Kilgus, C.C.; "Resonant Quadrafilar Helix"; IEEE Transactions on Antennas and Propagation, vol. AP-17: May 1969; pp. 349-351.
Kilgus, Dr. Charles C.; "Spacecraft and Ground Station Applications of the Resonant Quadrifilar Helix"; Digest of the 1974 Int. IEEE/Ap-5 Symposium; Jun. 1974; pp. 75-77.

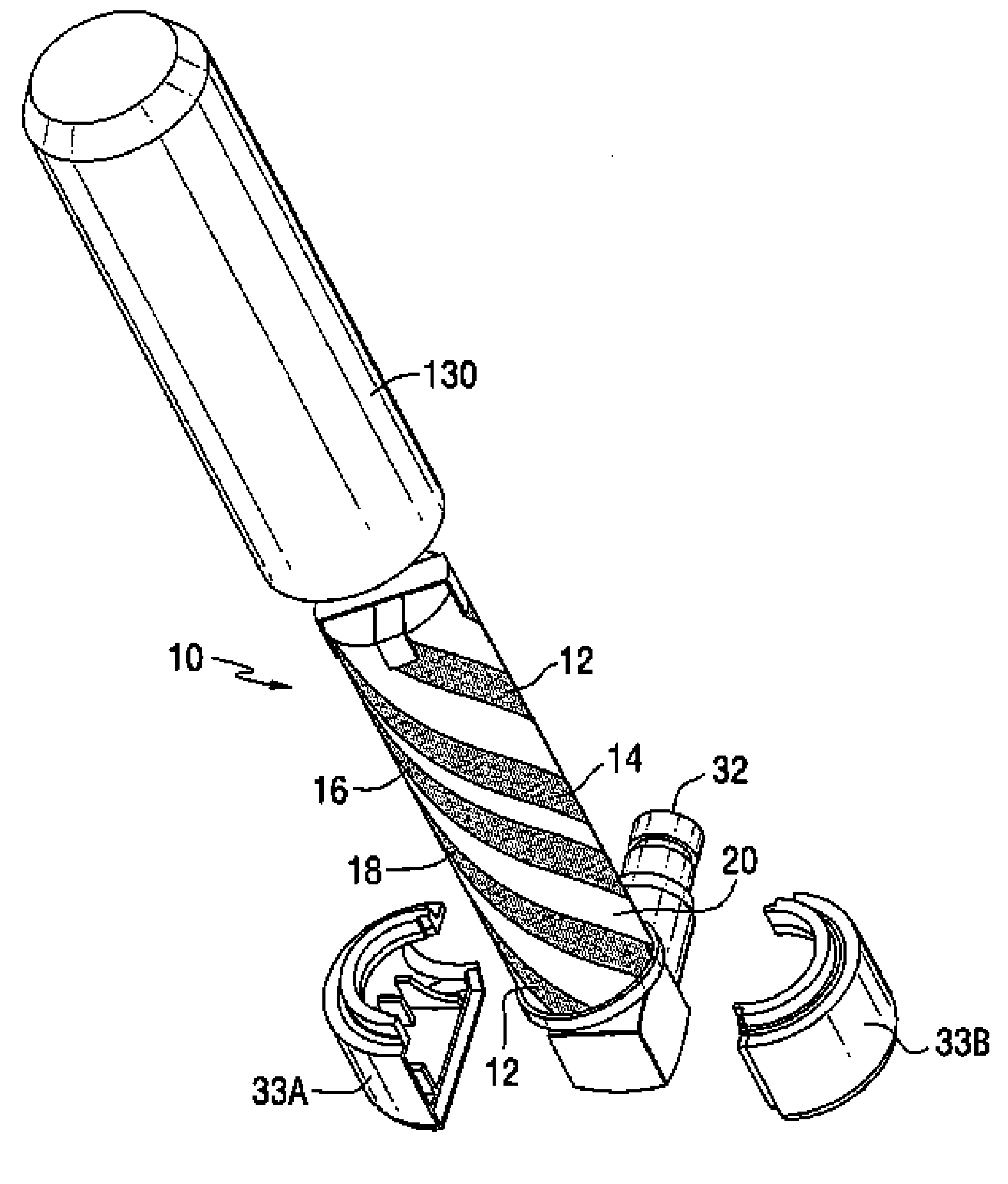
(Continued)

Primary Examiner—Trinh Vo Dinh
(74) *Attorney, Agent, or Firm*—John L. DeAngelis; Beusse, Wolter, Sanks, Mora & Maire, P.A.

(57) ABSTRACT

A quadrifilar helical antenna comprising two pairs of filars having unequal lengths and phase quadrature signals propagating thereon. A disk-like impedance matching element disposed at a lower end of the antenna matches a source impedance to an antenna impedance. In certain embodiments a first crossbar connector on a substrate disposed at an upper end of the antenna electrically connects two helical filars to form a first filar pair and a second crossbar connector disposed on the substrate connects two filars to form a second filar pair.

37 Claims, 10 Drawing Sheets



U.S. PATENT DOCUMENTS

6,407,720	B1	6/2002	Josypenko	
6,424,316	B1	7/2002	Leisten	
6,480,173	B1	11/2002	Marino	
6,483,471	B1	11/2002	Petros	
6,535,179	B1	3/2003	Petros	
6,545,649	B1	4/2003	Seavey	
6,608,604	B1	8/2003	Sharaiha et al.	
6,621,458	B1	9/2003	Petros et al.	
6,624,795	B2	9/2003	Boyle	
6,653,987	B1	11/2003	Lamensdorf et al.	
6,720,929	B2	4/2004	Nybeck et al.	
2003/0016184	A1 *	1/2003	Kitching et al.	343/895

OTHER PUBLICATIONS

Kilgus, Chares C.; "Shaped-Conical Radiation Pattern Performance of the Backfire Quadrifilar Helix"; IEEE Transactions on Antennas and Propagation; May 1975; pp. 392-397.

Ruperto, Eugene F.; "If your existing VHF Omnidirectional antenna coverage is "just okay", this twisted 'tenna is probably just what you need!"; date unknown; pp. 1-9.

Marini, Domenico; "Experimental Investigation of Quadrifilar Helix Antennas for 2400 MHz"; The AMSAT Journal May/Jun. 2004; pp. 6-10.

* cited by examiner

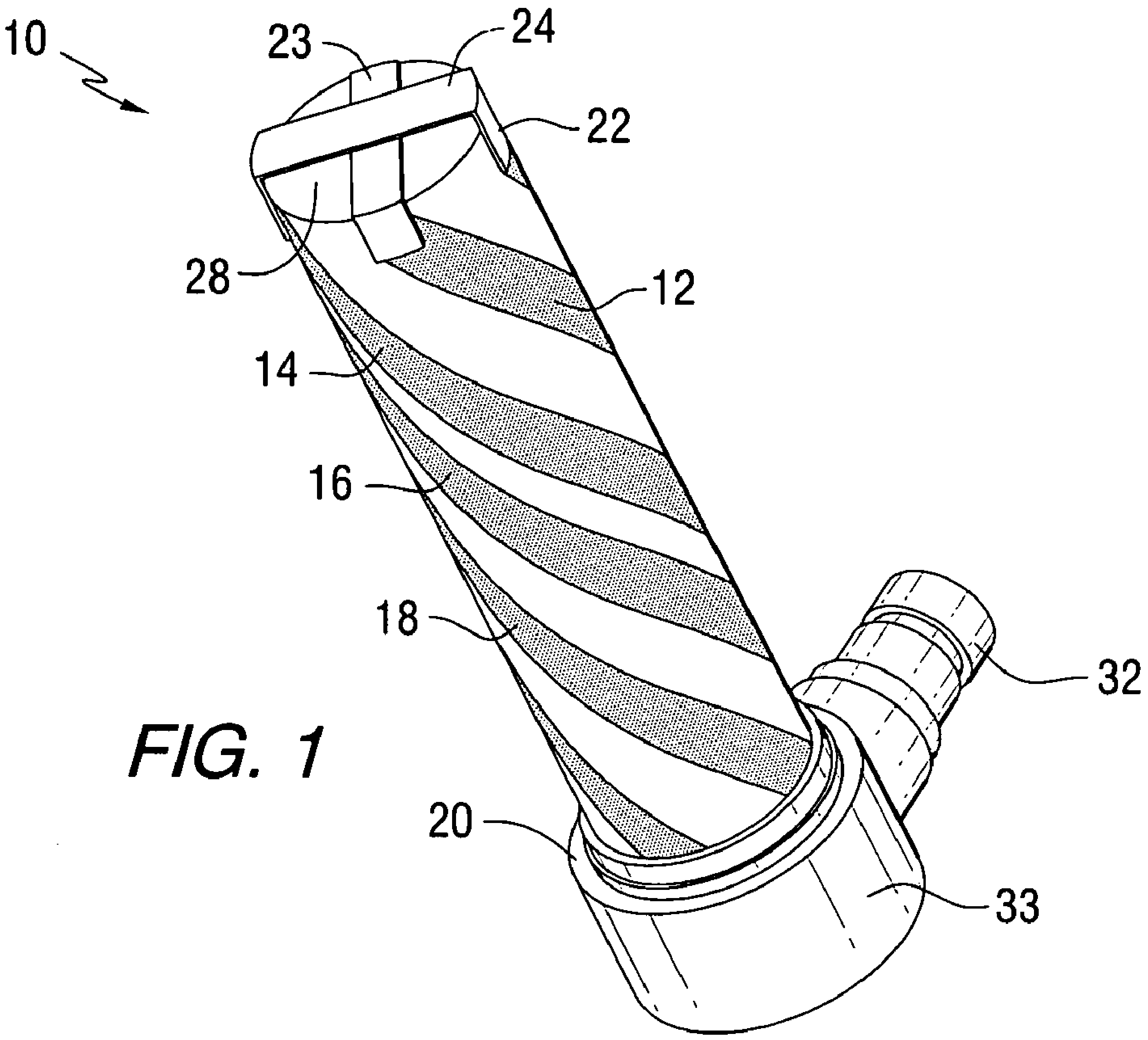


FIG. 1

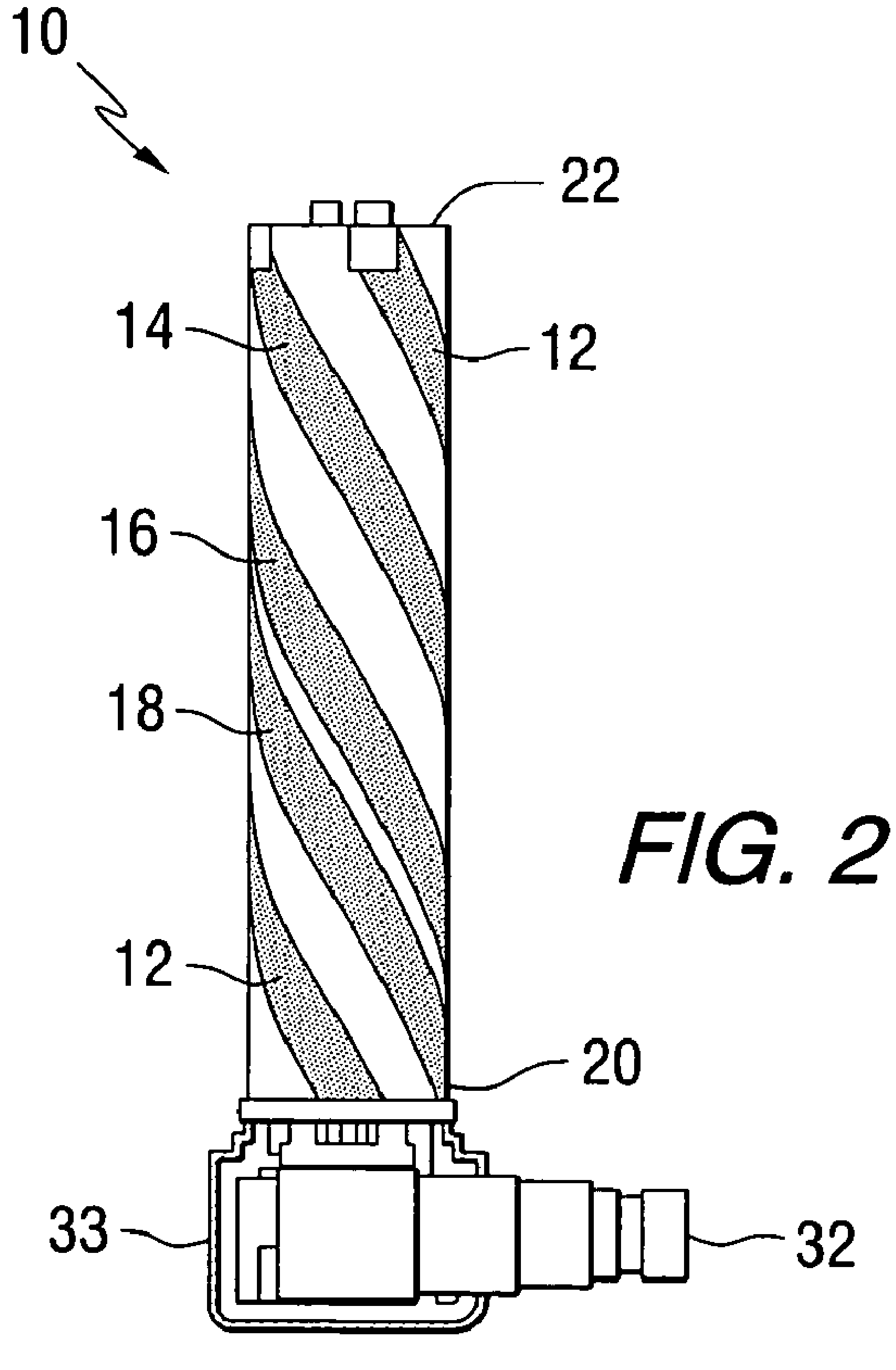


FIG. 2

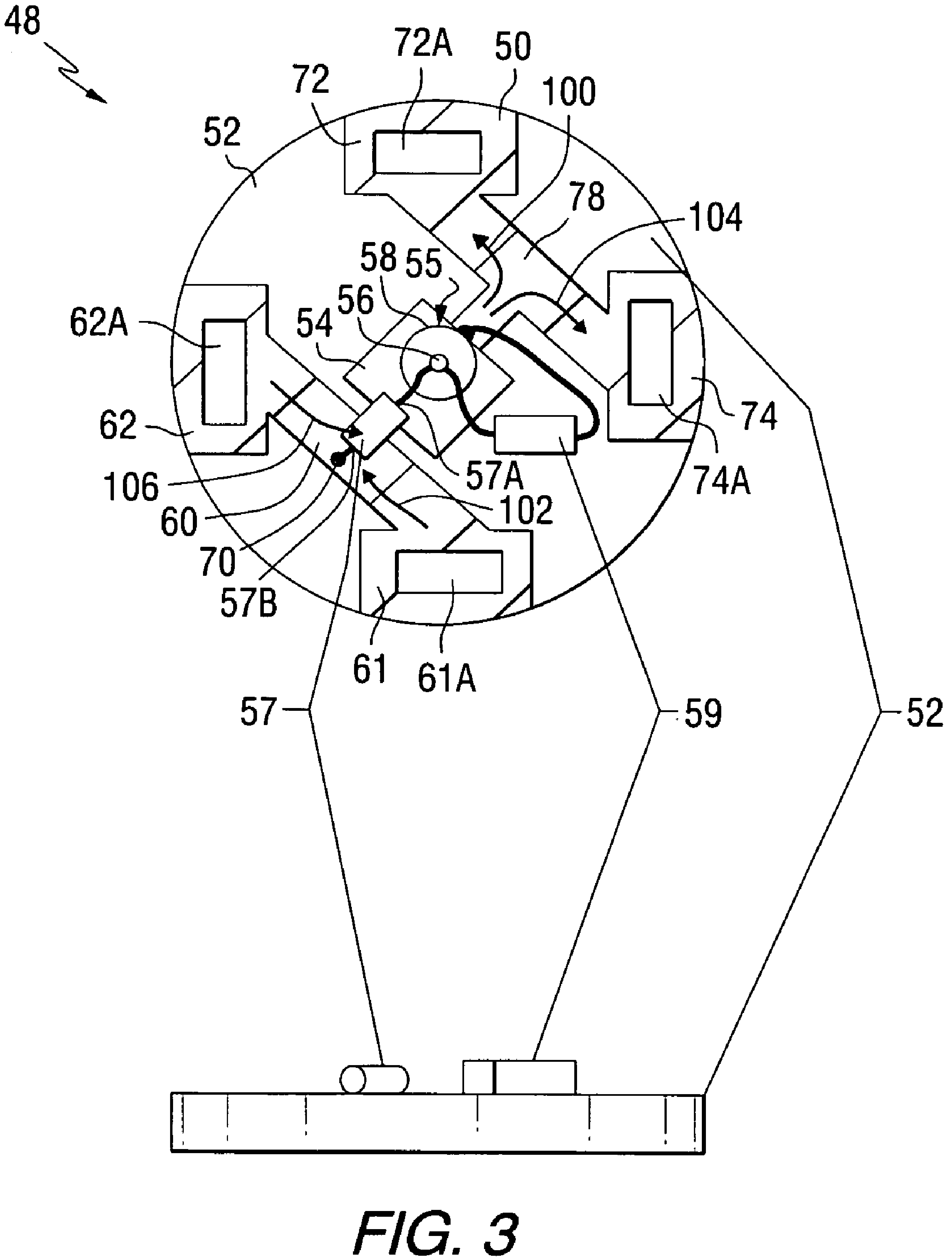

48
72A
50
72
100
52
78
104
58
55
56
62A
54
74
62
57A
106
74A
102
60
70
57B
61
61A
57
59
52

FIG. 3

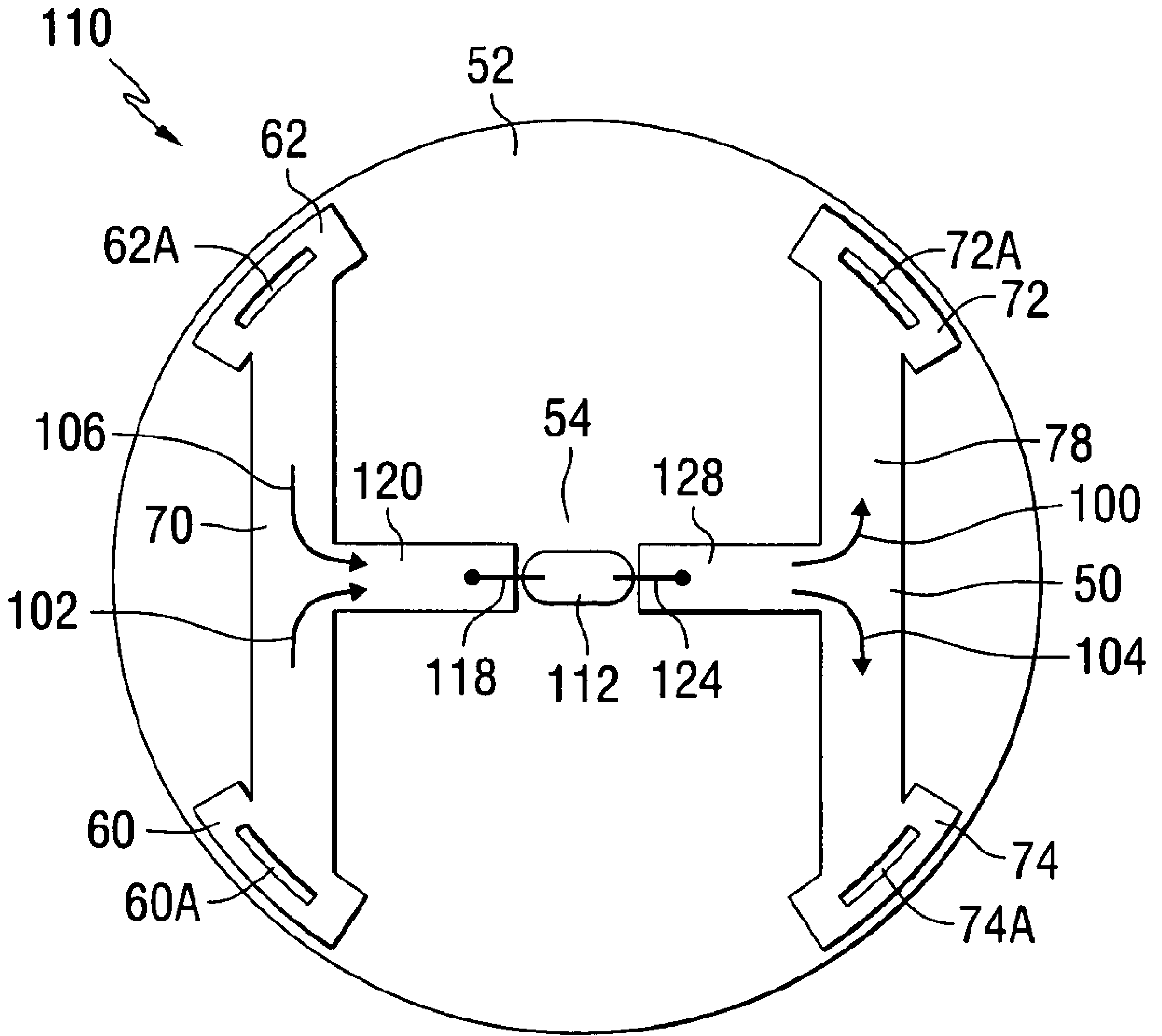

110
52
62
62A
72A
72
54
106
120
128
78
70
100
50
102
104
118
112
124
60
74
60A
74A

FIG. 4

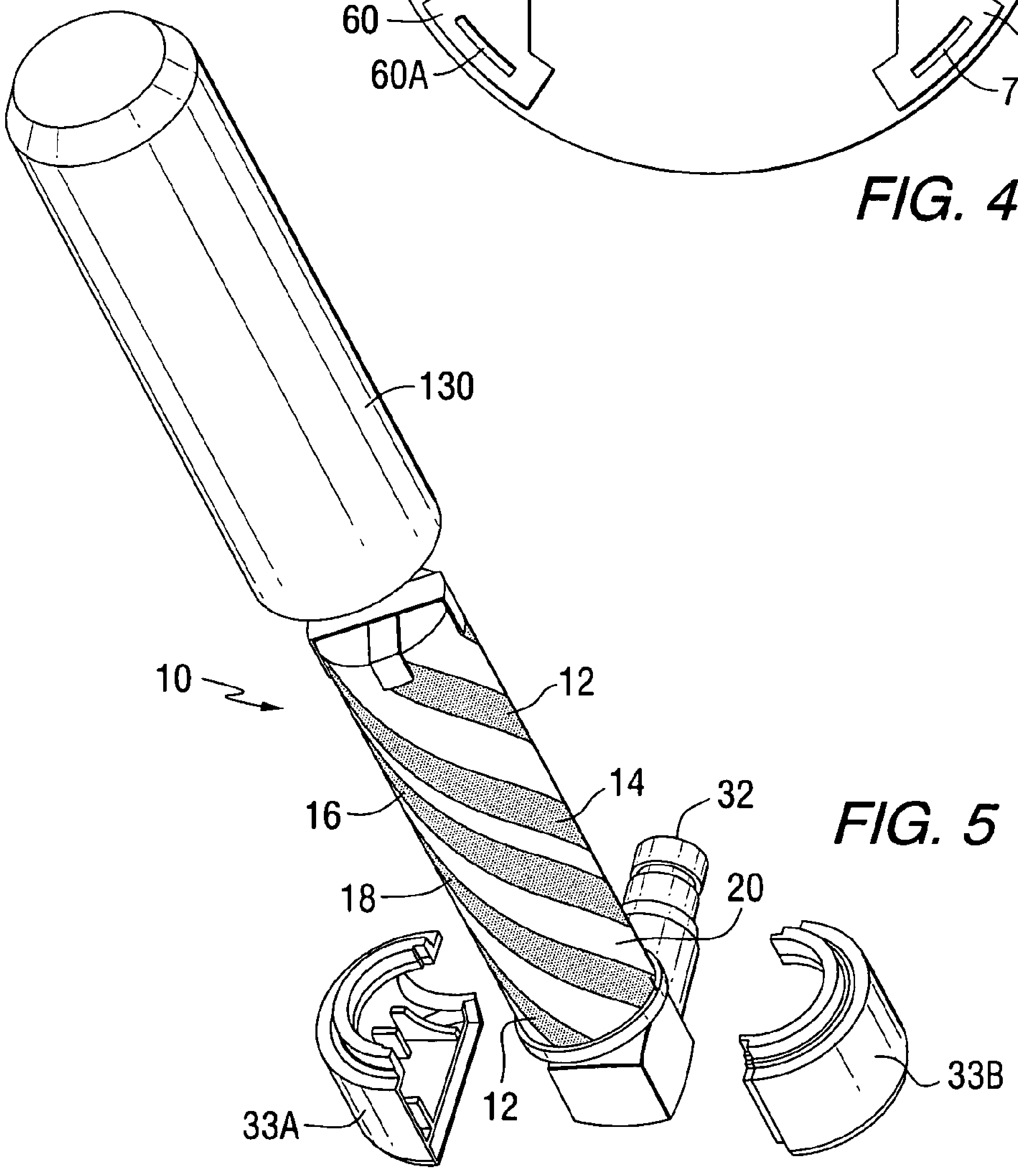

130
10
12
14
32
16
20
18
12
33B
33A

FIG. 5

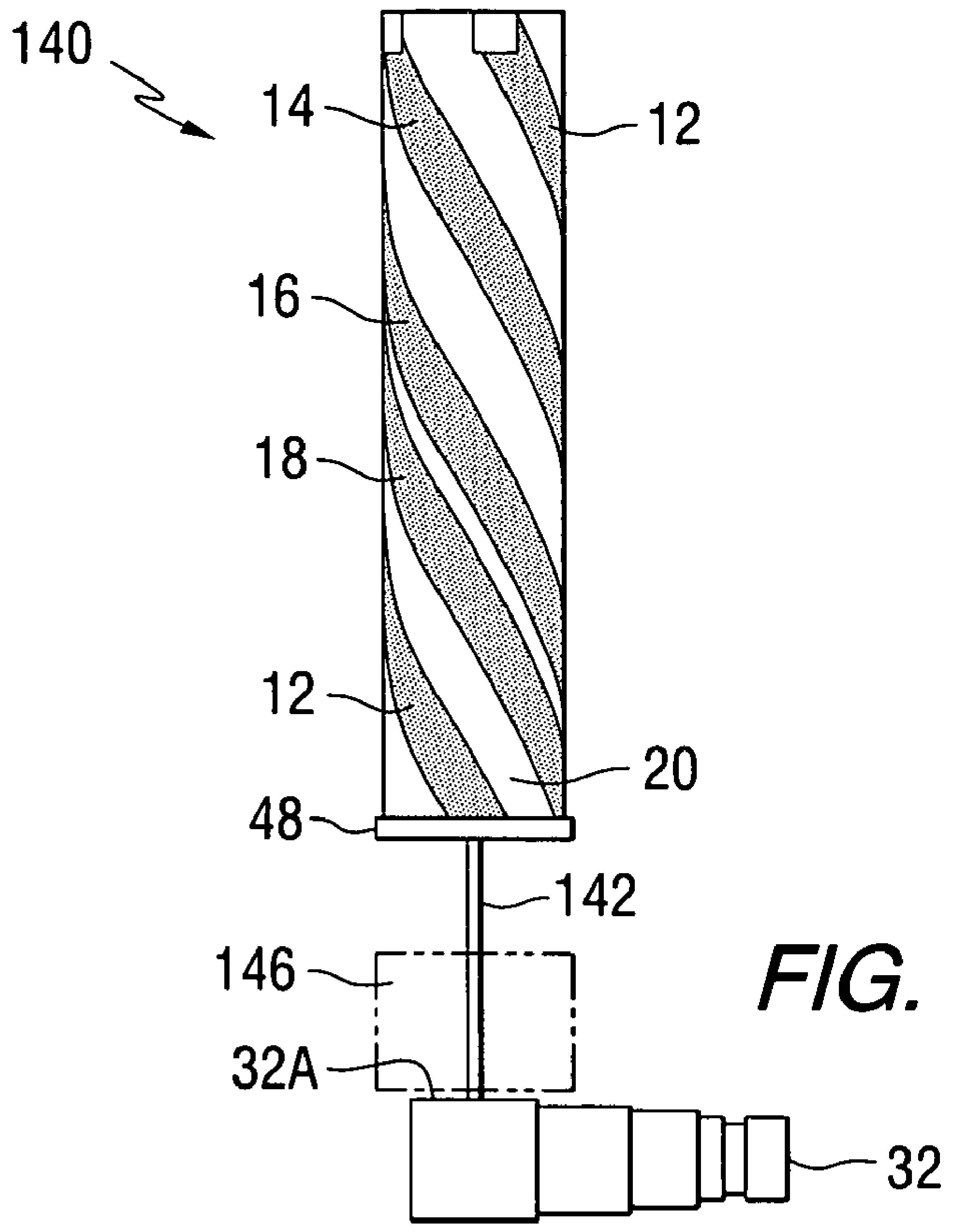


FIG. 6

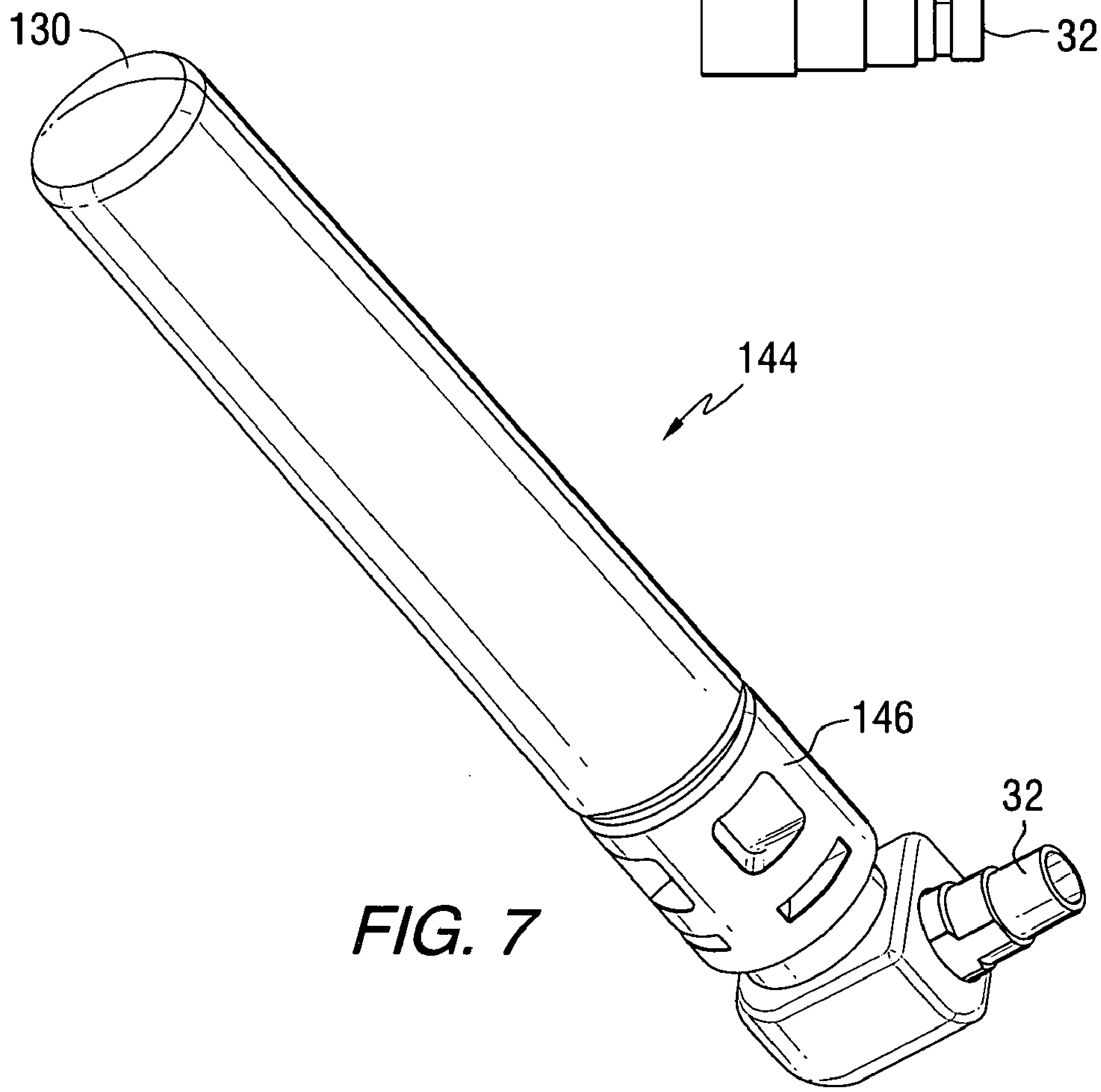


FIG. 7

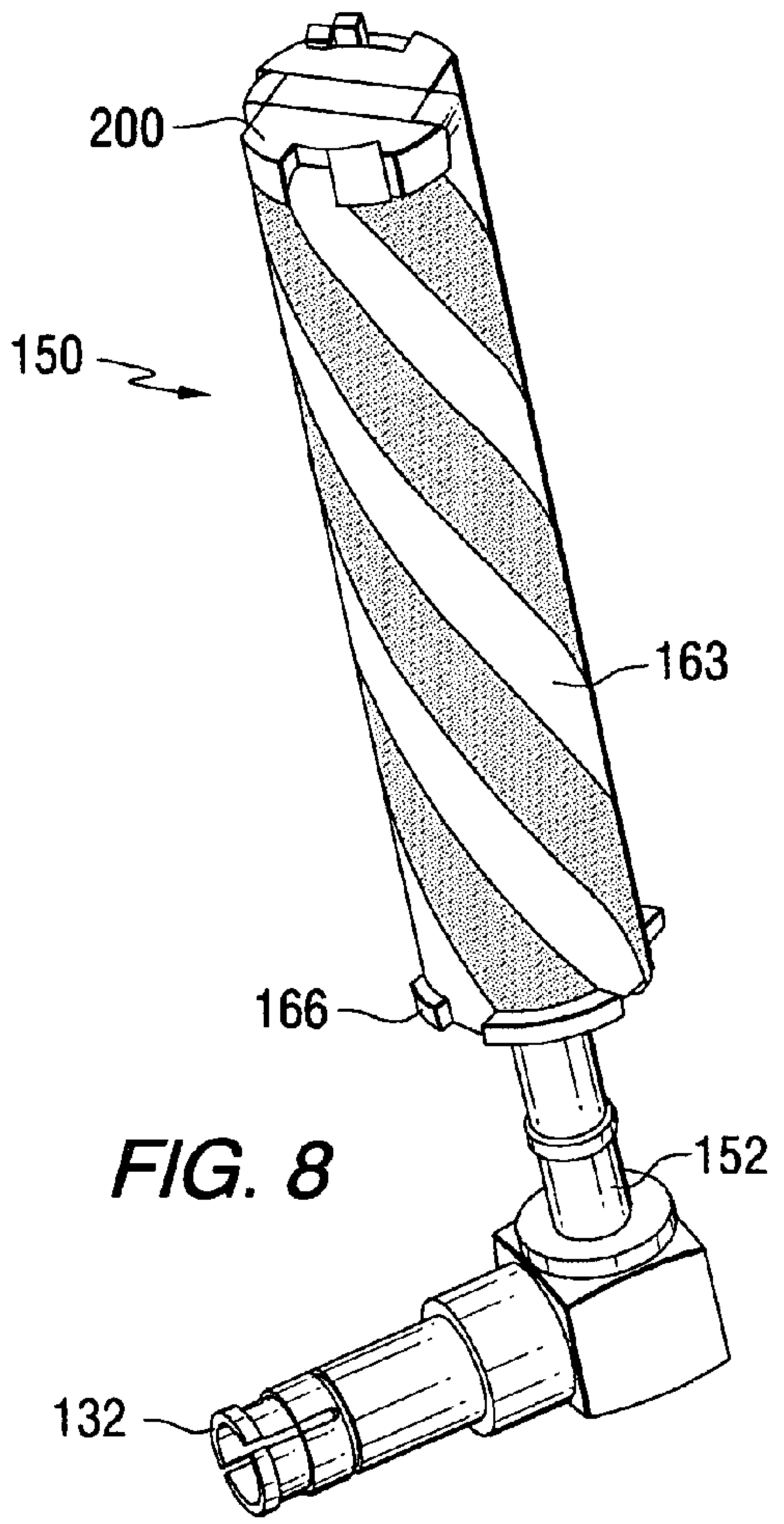


FIG. 8

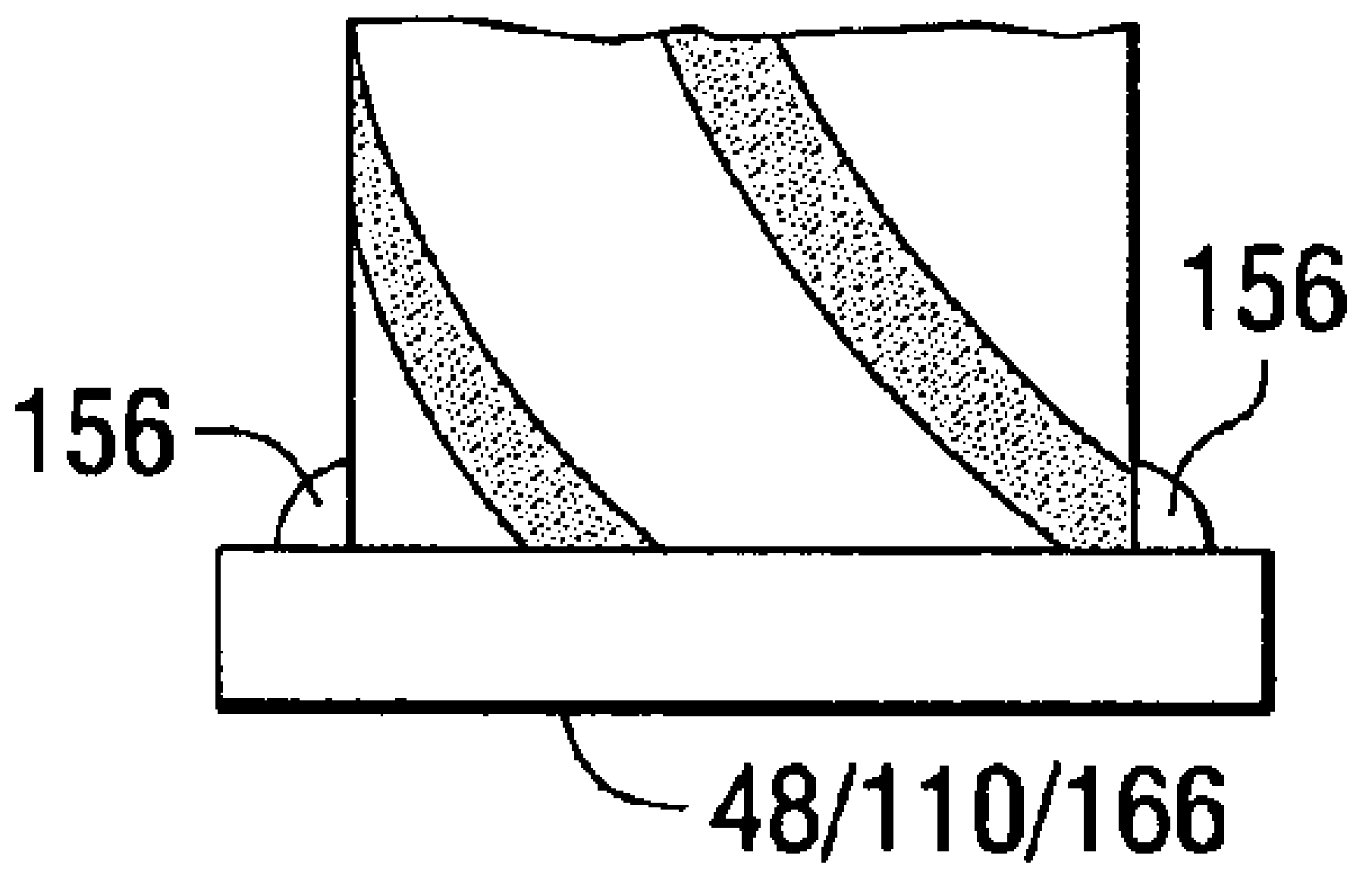


FIG. 9

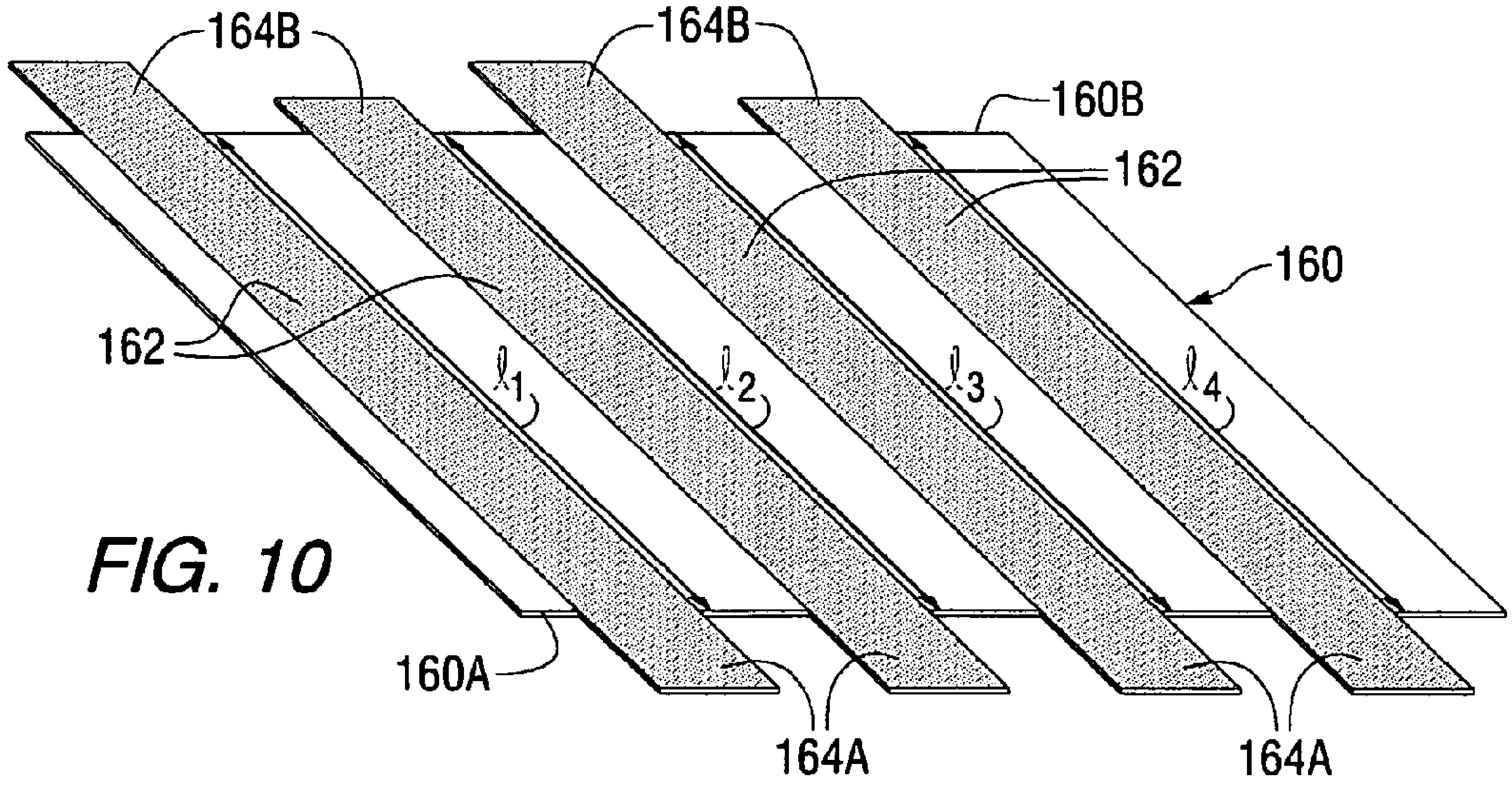


FIG. 10

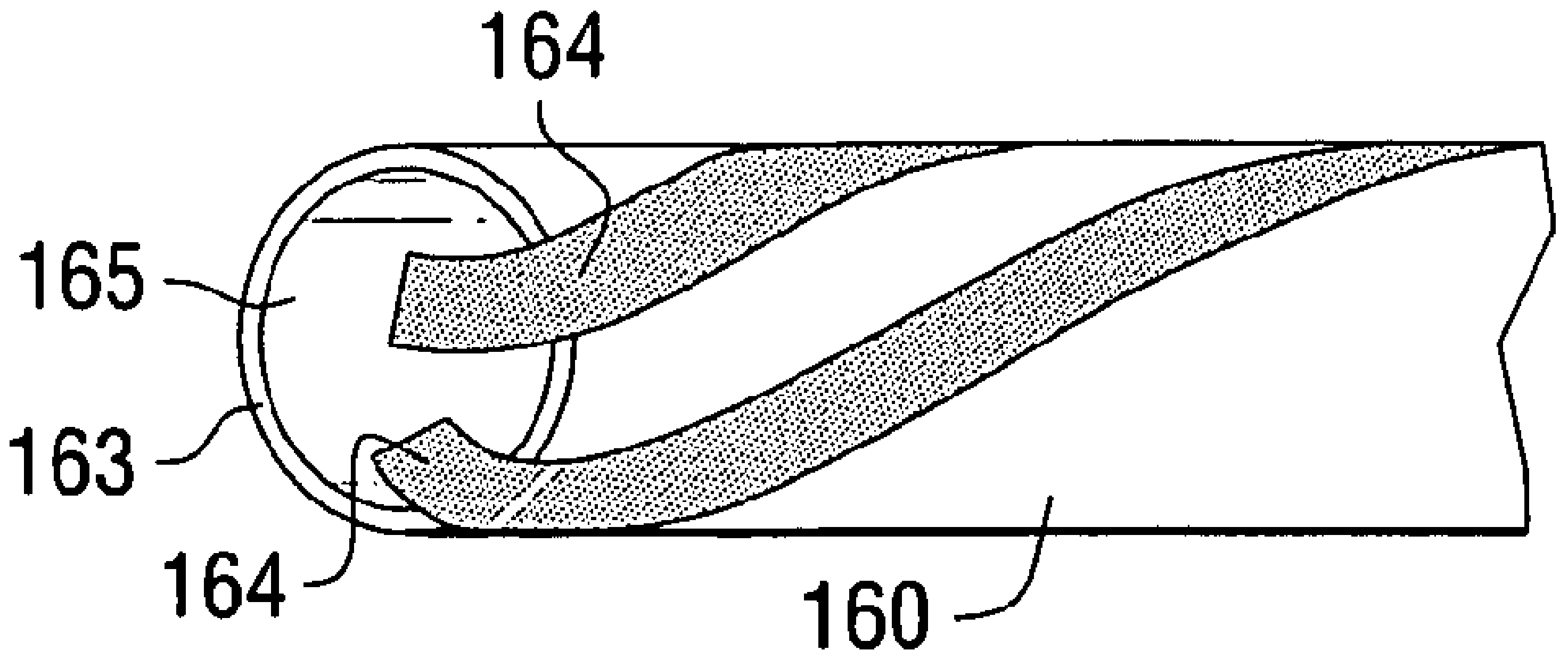


FIG. 11

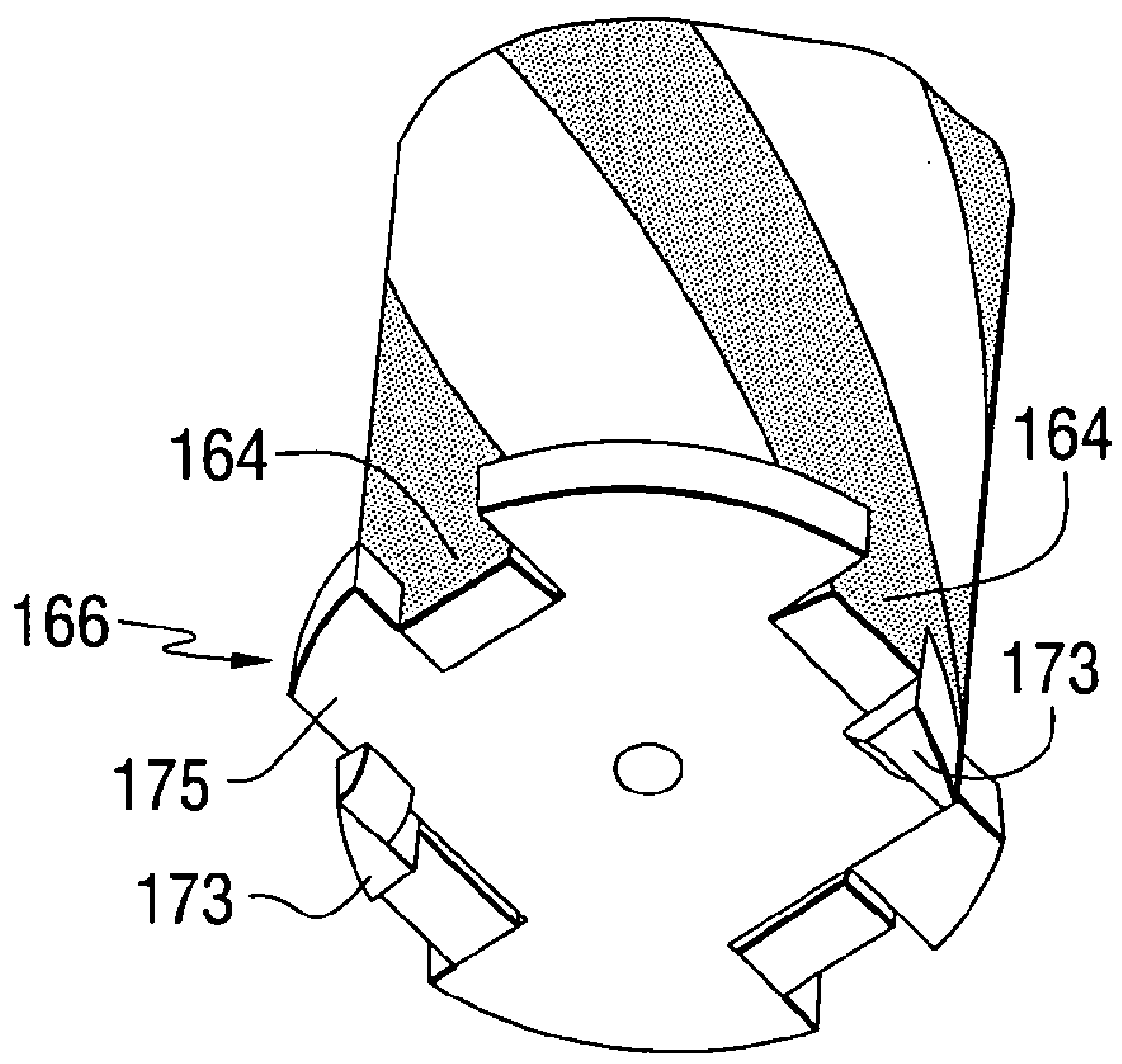


FIG. 13

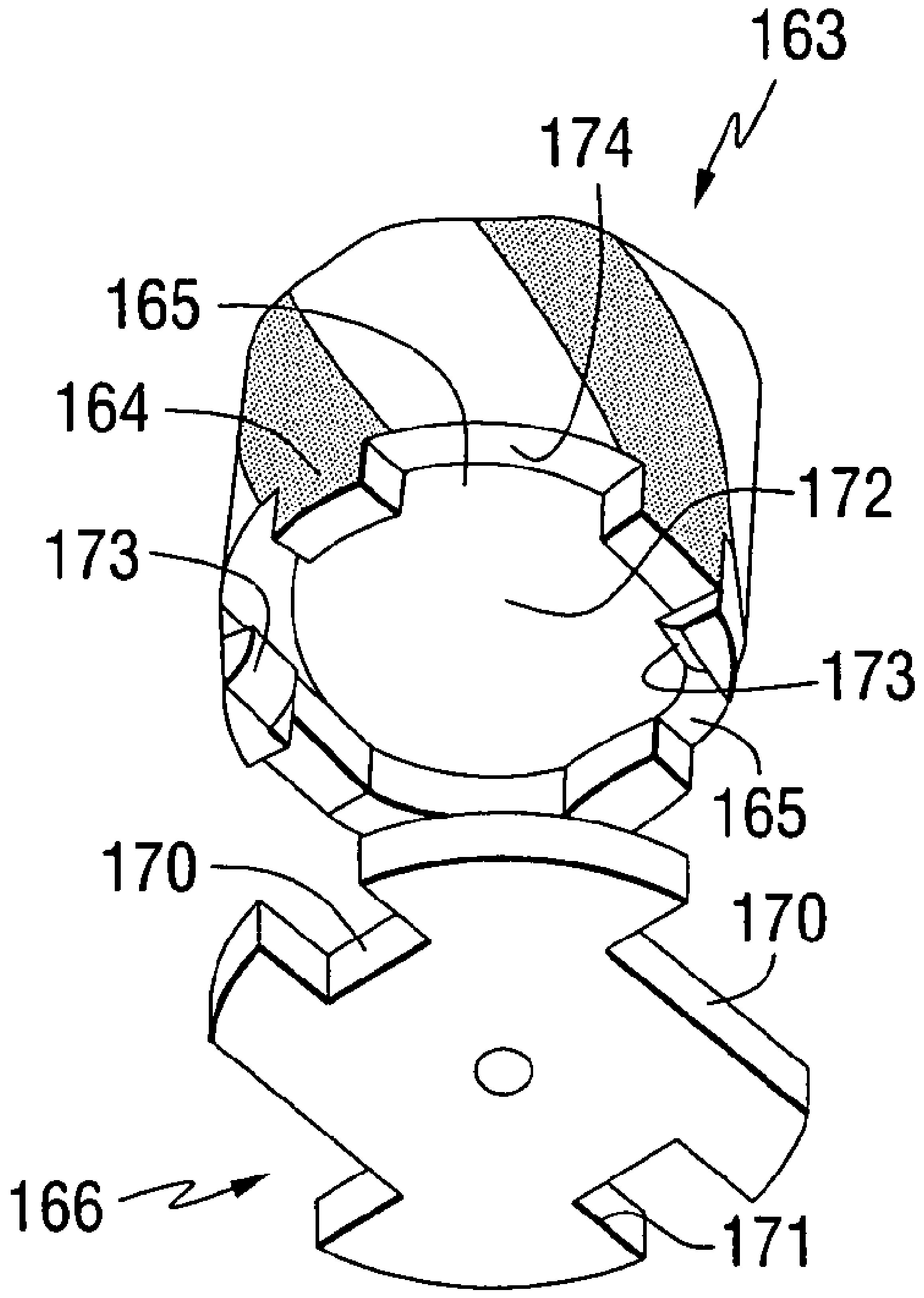


FIG. 12

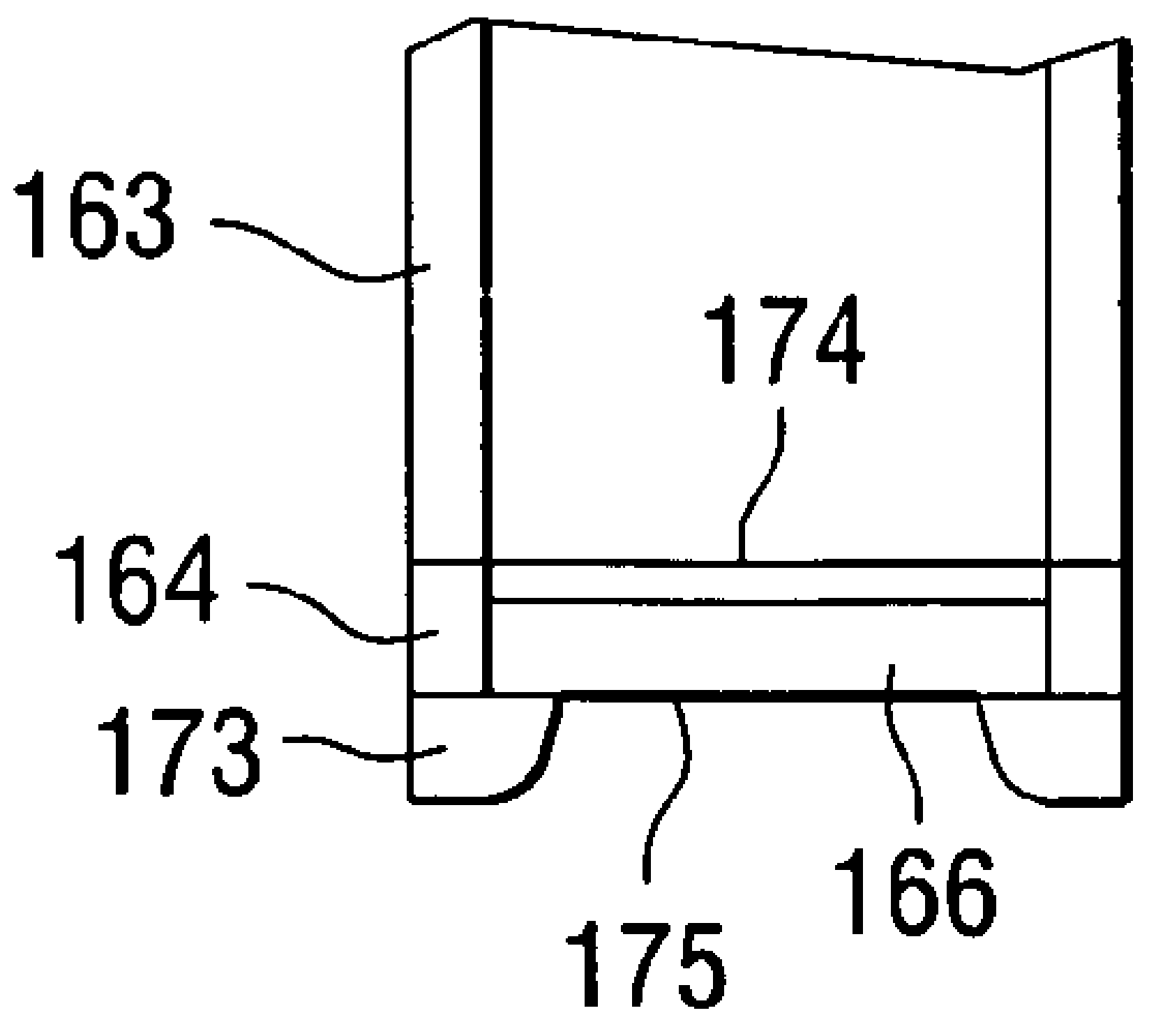


FIG. 14

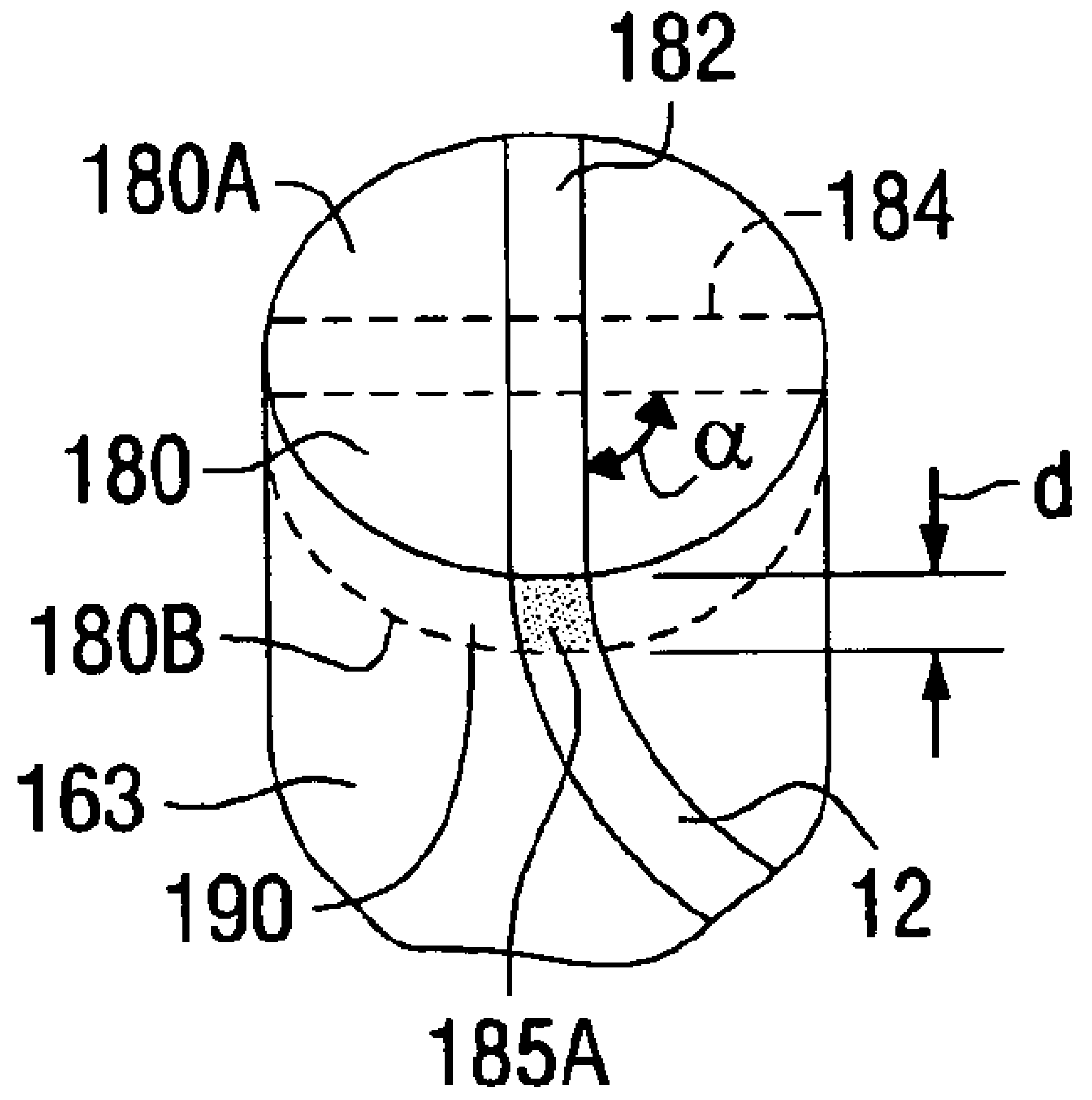


FIG. 15

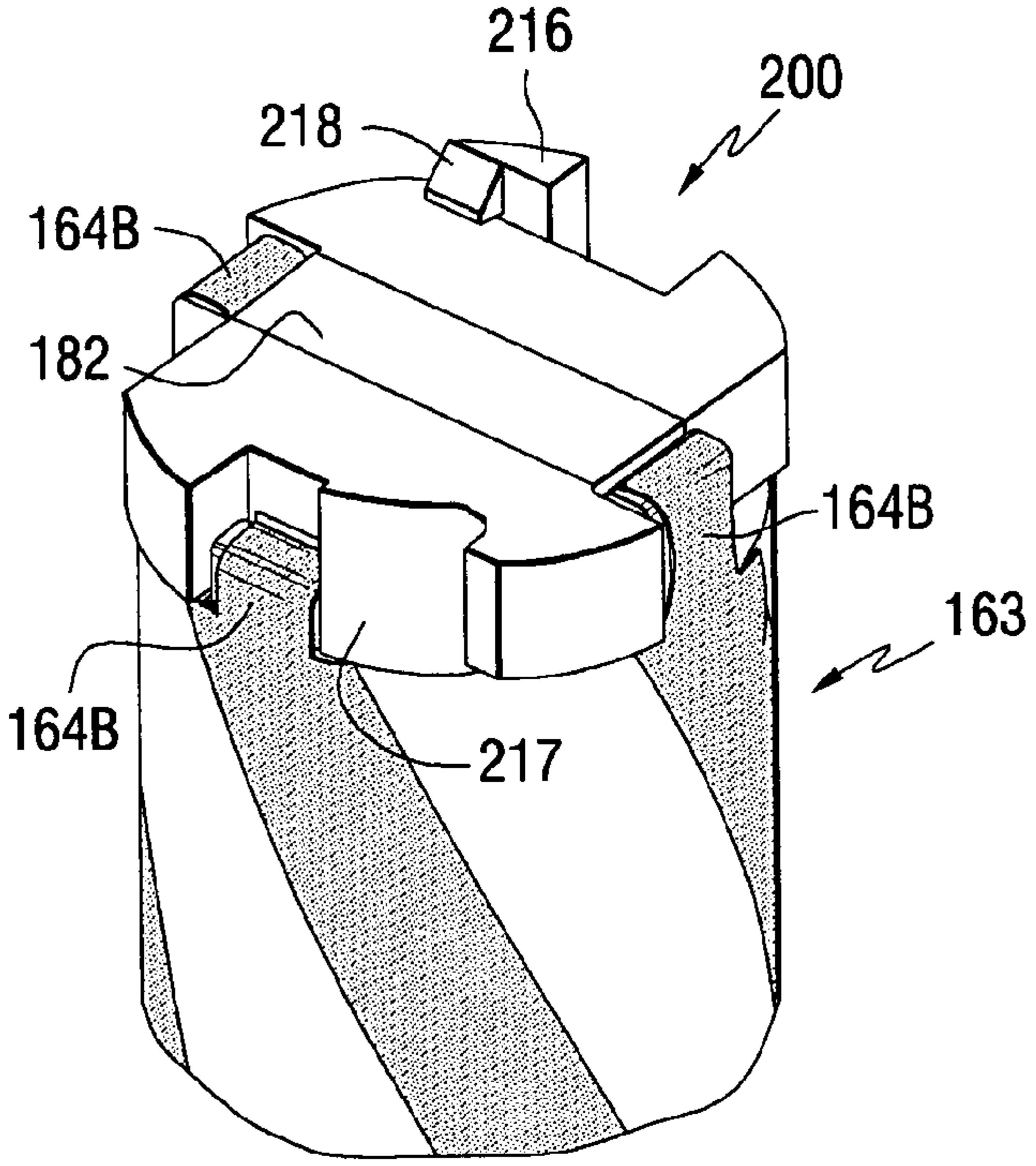


FIG. 16

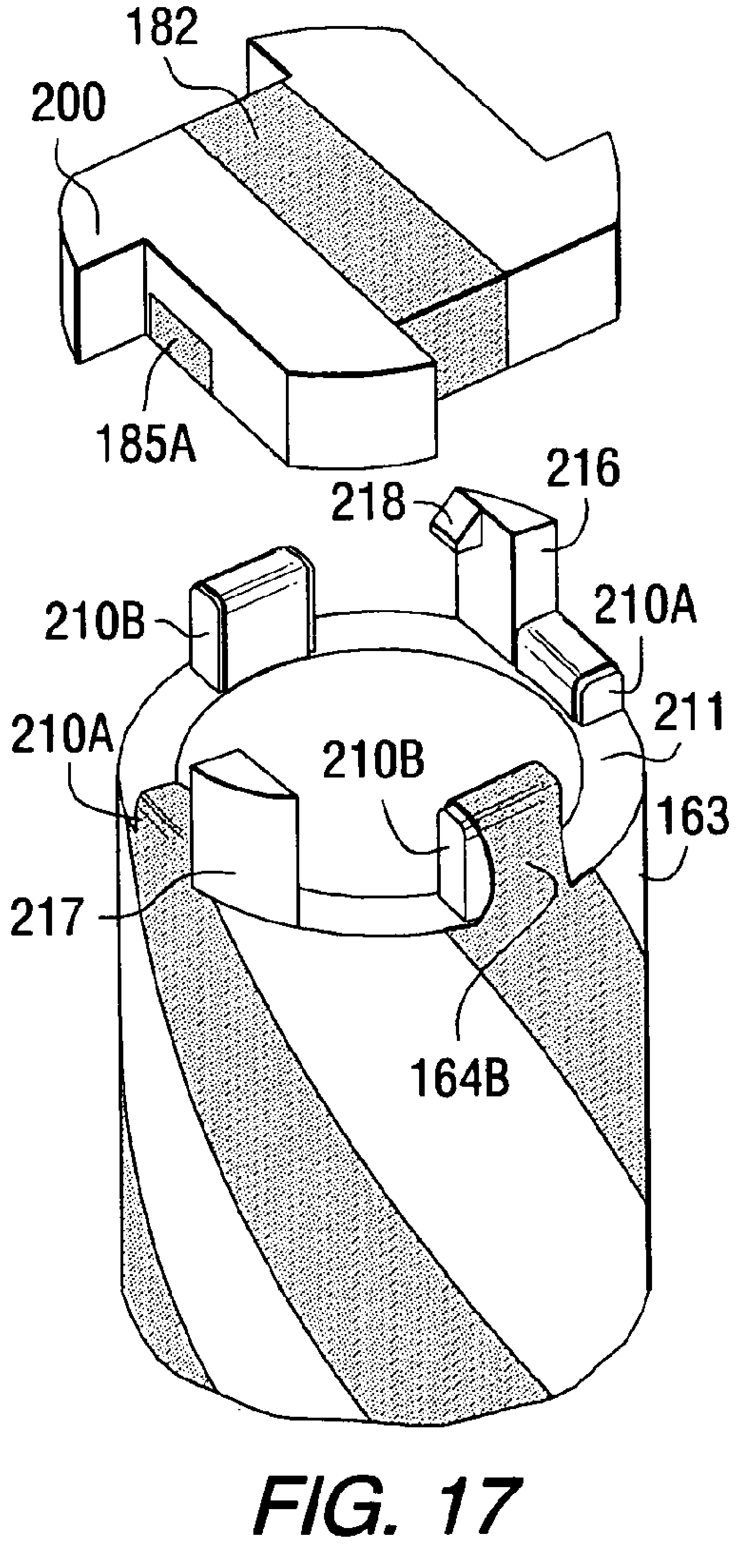


FIG. 17

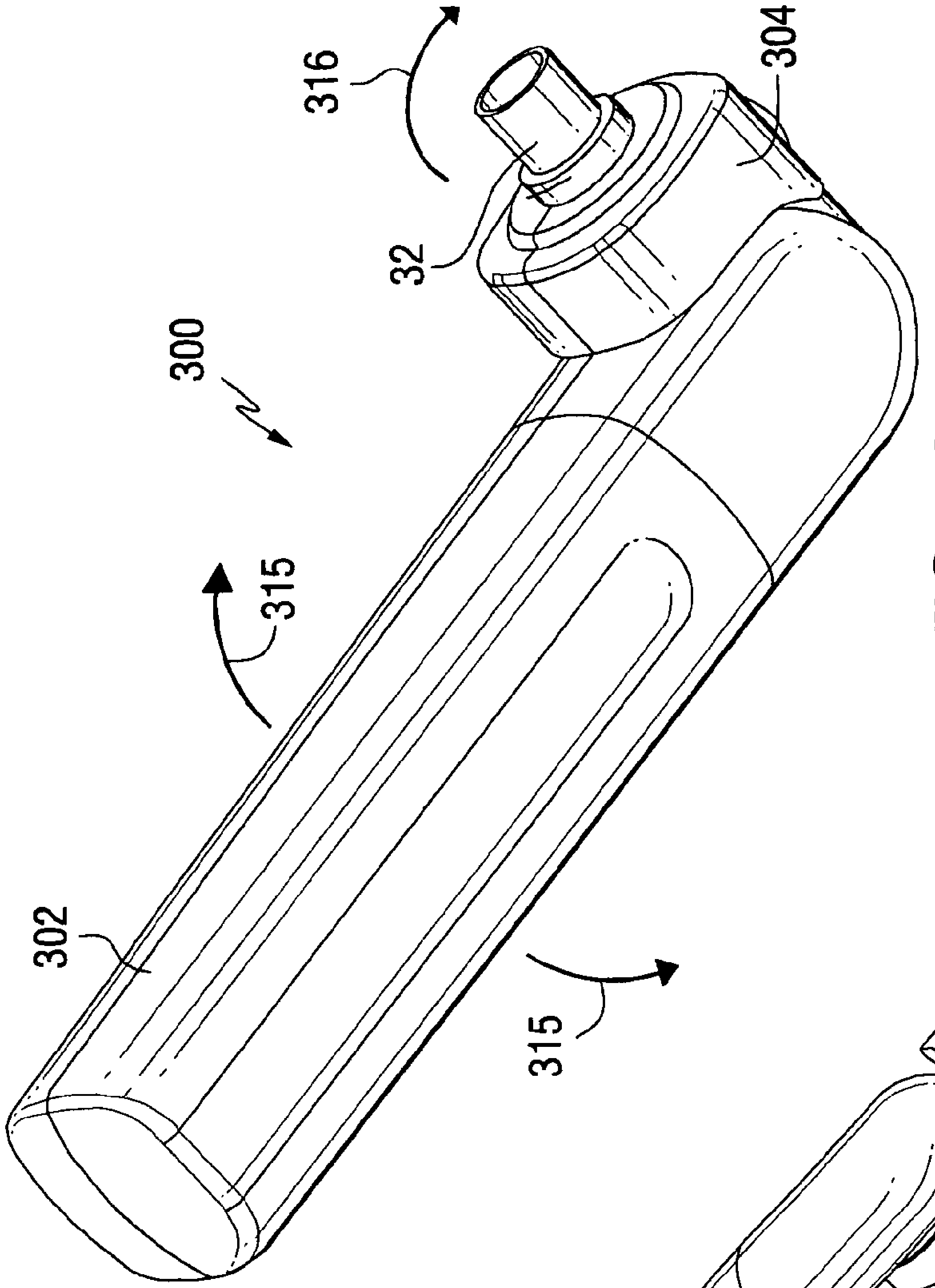


FIG. 19

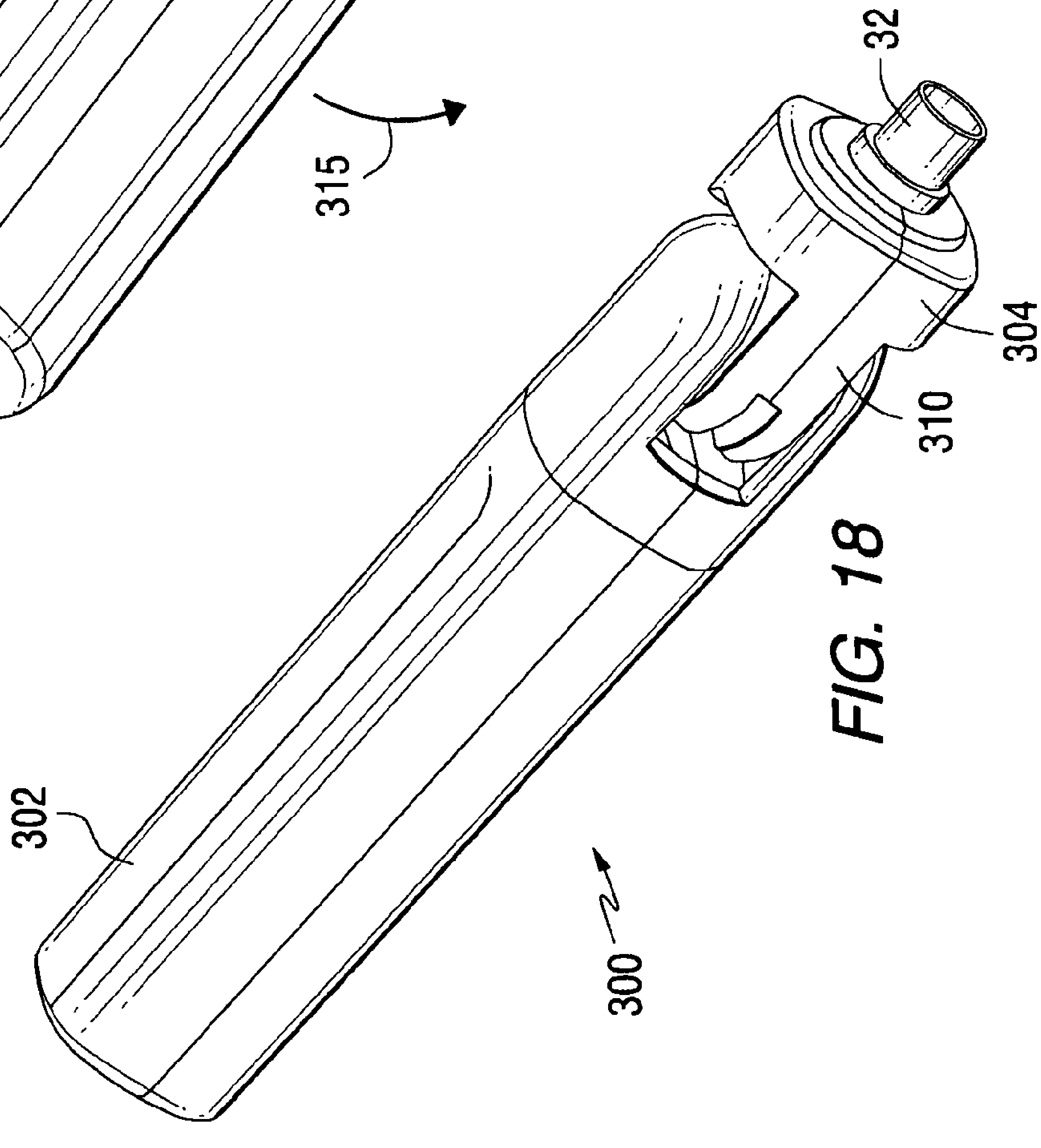


FIG. 18

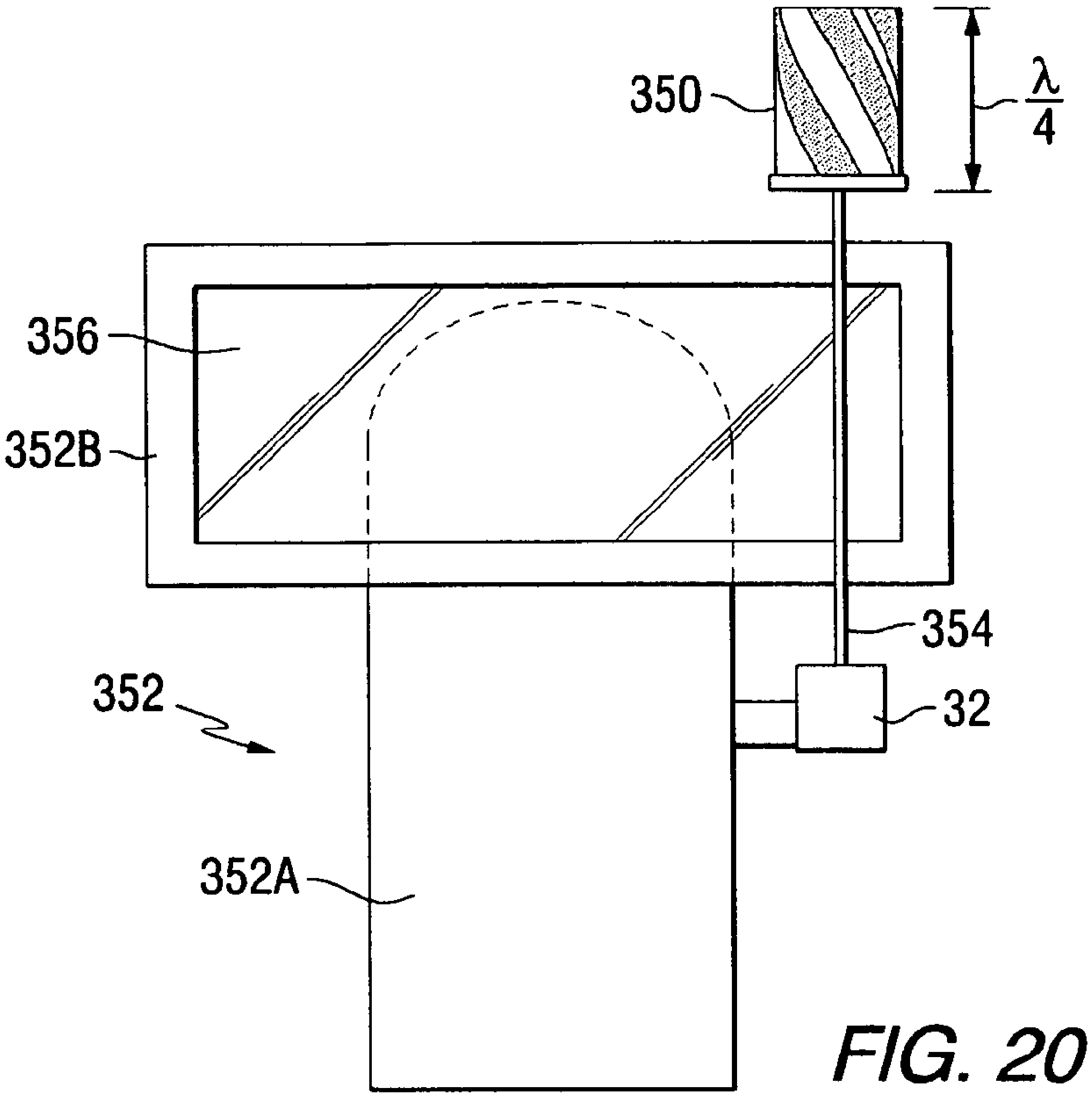


FIG. 20

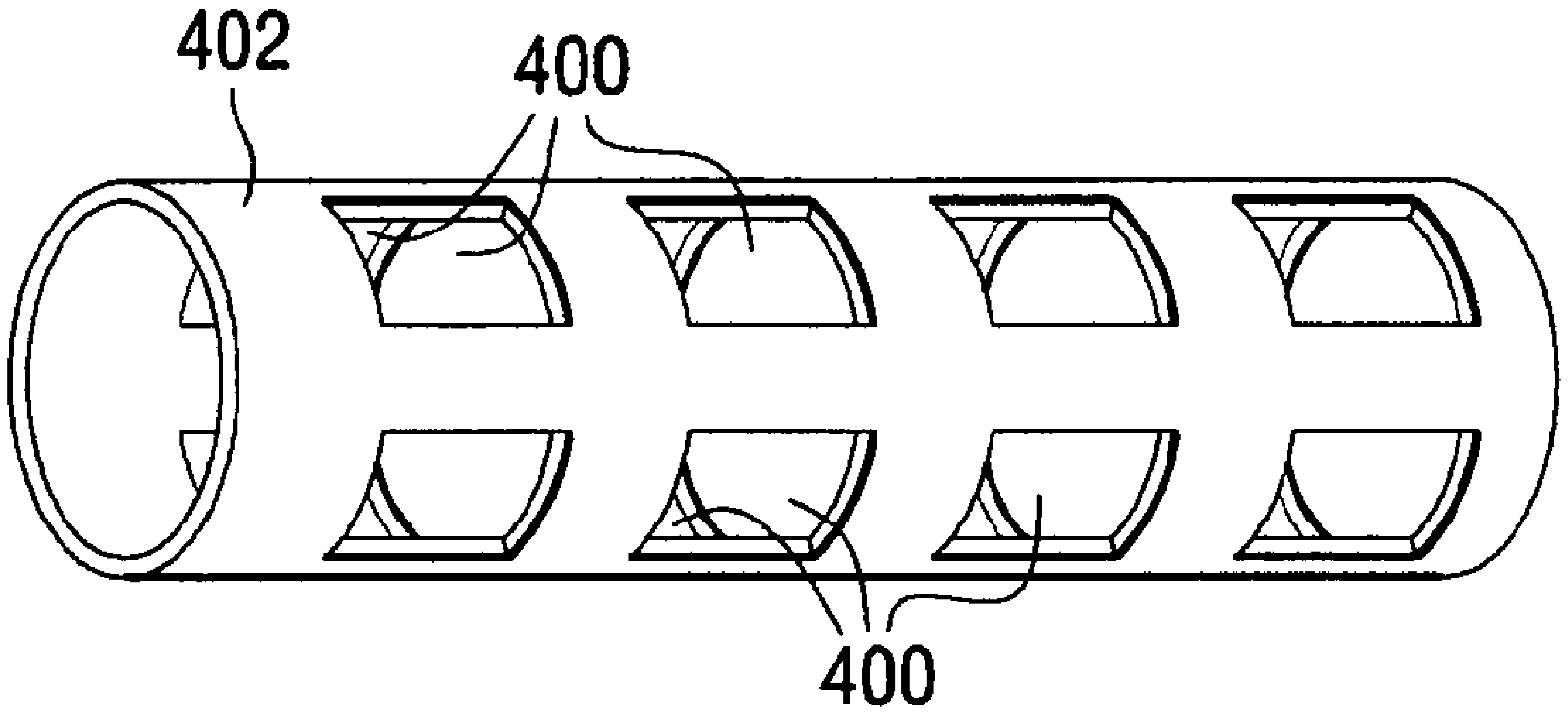


FIG. 21

FIG. 22

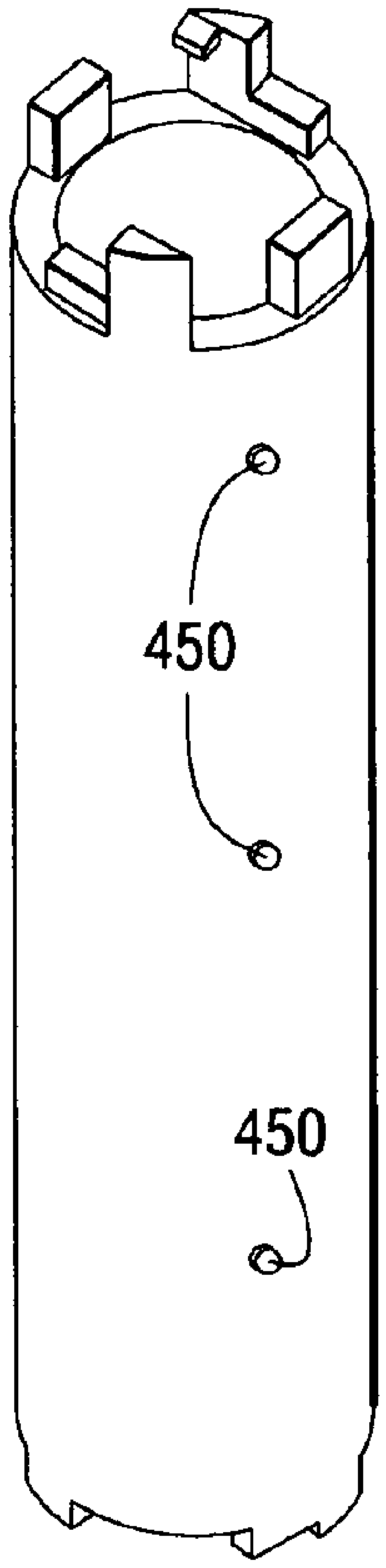


FIG. 23

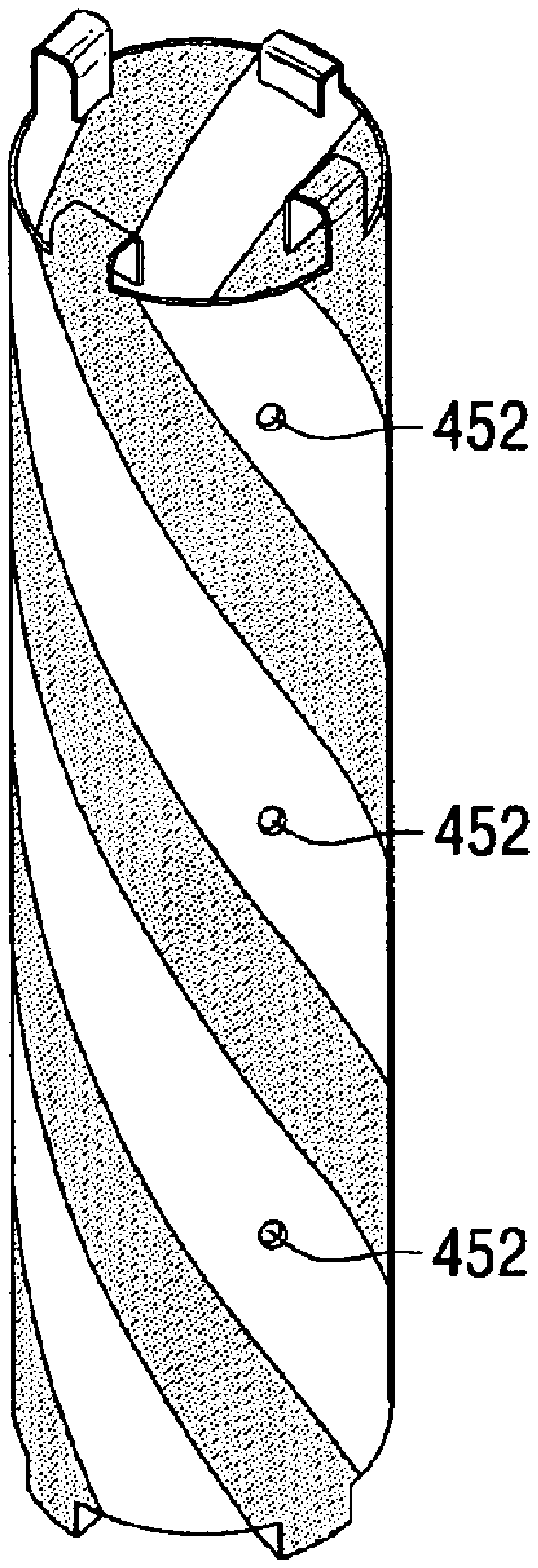


FIG. 24

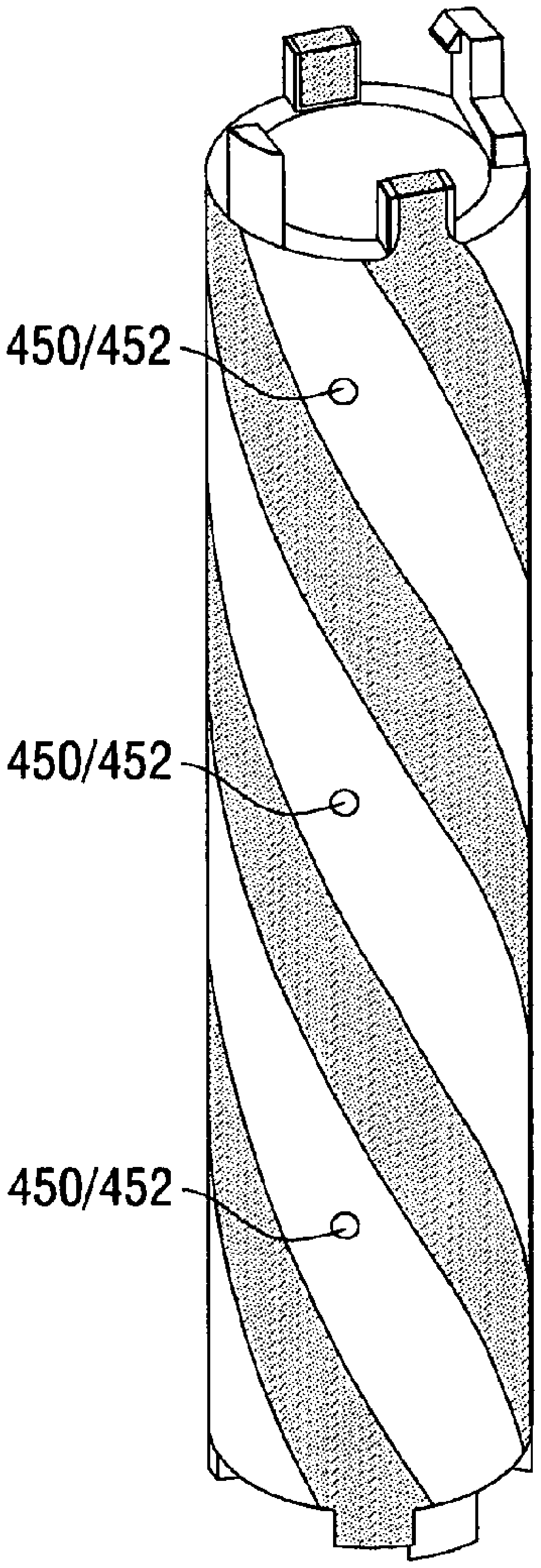


FIG. 25

HANDSET QUADRIFILAR HELICAL ANTENNA MECHANICAL STRUCTURES

CROSS-REFERENCE TO RELATED APPLICATIONS

This patent application is a continuation-in-part application claiming the benefit of the patent application assigned Ser. No. 10/998,301 filed on Nov. 26, 2004 and entitled Quadrifilar Helical Antenna, which claims the benefit of the provisional patent application assigned Ser. No. 60/592,011 filed on Jul. 28, 2004.

FIELD OF THE INVENTION

The present invention relates to an antenna for use in a satellite communications link, and in particular to a quadrifilar helical antenna (QHA) for use in a satellite communications link.

BACKGROUND OF THE INVENTION

A helical antenna comprises one or more elongated conductive elements wound in the form of a screw thread to form a helix. The geometrical helical configuration includes electrically conducting elements of length L arranged at a pitch angle P about a cylinder of diameter D. The pitch angle is defined as an angle formed by a line tangent to the helical conductor and a plane perpendicular to a helical axis. Antenna operating characteristics are determined by the helix geometrical attributes, the number and interconnections between the conductive elements, and the feed arrangement. When operating in an end fire or forward radiating axial mode the radiation pattern comprises a single major pattern lobe. The pitch angle determines the position of maximum intensity within the lobe. Low pitch angle helical antennas tend to have the maximum intensity region along the axis; for higher pitch angles the maximum intensity region is off-axis.

Quadrifilar helical antennas (QHA) are used for communication and navigation receivers operating in the UHF, L and S frequency bands. A resonant QHA with limited bandwidth is also used for receiving GPS signals. The QHA has a relatively small size, excellent circular polarization coverage and a low axial ratio over most of the upper hemisphere field of view. Since the QHA is a resonant antenna, its dimensions are typically selected to provide optimal performance for a narrow frequency band. C. C. Kilgus first described the QHA in "Resonant Quadrifilar Helix," IEEE Transactions on Antennas and Propagation, Vol. AP-17, May 1969, pp. 349–351.

One prior art quadrifilar helical antenna comprises four equal length filars mounted on a helix having a diameter of about 30 mm for operation at about 1575 MHz. Given these geometrical features, the antenna presents a driving point impedance of about 50 ohms, which is suitable for matching to a common 50 ohm characteristic impedance coaxial cable. The four filars of the QHA are fed in phase quadrature, i.e., a 90 degrees phase relationship between adjacent filars. There are at least two known prior art techniques for quadrature feeding of the four equal-length QHA filars. One such quadrature matching structure employs a lumped or distributed branch line hybrid coupler (BLHC) and a terminating load, together with two lumped or distributed baluns. Another technique that offers a somewhat broader bandwidth uses three branch line hybrid couplers (a first input BLHC receiving the input signal and providing an output

signal to two parallel BLHC'S) each operative with a terminating load. A quarter wave phase shifter provides a 90 degrees phase shift between the first BLHC and one of the parallel-connected BLHC'S.

It is known that such quadrature matching techniques, such as hybrid couplers and baluns, disadvantageously increase the size of the printed circuit board on which the antenna is mounted. The couplers and baluns also increase the antenna cost, and each additional component operative with the antenna imposes losses and bandwidth limitations.

Typically, the QHA is a self-sufficient radiating structure operated without a ground plane or counterpoise. However, when the QHA is installed in close proximity to a radio transceiver handset, the handset structure can induce electromagnetic wave reflections that influence the QHA's radiation pattern and impedance, much like a ground plane. For example, if the QHA emits a right-hand circularly polarized signal, upon reflection from a conducting surface, the signal is transformed to a left-hand circularly polarized signal. Obviously, such effects negatively influence the antenna's performance, and can be particularly troublesome if the communications system employs dual signal polarizations.

BRIEF SUMMARY OF THE INVENTION

According to one embodiment of the invention, a quadrifilar helical antenna, comprises a substantially cylindrical substrate; a first pair of serially connected helical filars having a first length and disposed on the substrate, the first pair of filars having a first end and a second end; a second pair of serially connected helical filars having a second length different than the first length and disposed on the substrate, the second pair of filars having a third and a fourth end and an impedance matching element conductively connected to the first, the second, the third and the fourth ends for matching an antenna impedance to a source impedance.

According to another embodiment of the invention, a handset communications device comprises a base; a cover movably engaged with the base for manipulation into different orientations with respect to the base and a quadrifilar helical antenna disposed in the base. The antenna comprises a substantially cylindrical substrate; a first, a second, a third and a fourth helical filar disposed on the substrate, wherein at least two of the first, the second, the third and the fourth filars have a different length; an impedance matching element conductively connected to the first, second, third and fourth filars for matching an antenna impedance to a source impedance and a connector disposed between the impedance matching element and the base.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other features of the present invention will be apparent from the following more particular description of the invention as illustrated in the accompanying drawings, in which like reference characters refer to the same parts throughout the different figures. The drawings are not necessarily to scale, emphasis instead being placed upon illustrating the principles of the invention.

FIGS. **1** and **2** illustrate different views of a QHA according to the teachings of the present invention.

FIG. **3** illustrates an impedance matching element, according to the teachings of the present invention, for use with the QHA of FIGS. **1** and **2**.

FIG. **4** illustrates another embodiment of an impedance matching element according to the teachings of the present invention.

FIG. **5** illustrates a QHA according to the present invention including a radome.

FIGS. **6**–**8** illustrate other embodiments of a QHA according to the present invention.

FIG. **9** illustrates solder filets for connecting the impedance matching element and the QHA.

FIG. **10** illustrates a substrate for use in fabricating a QHA according to the present invention.

FIG. **11** illustrates another embodiment of a QHA of the present invention including a mandrel.

FIGS. **12**–**14** illustrate an embodiment of an impedance matching element for use with the QHA.

FIG. **15**–**17** illustrate various embodiments of conductive bridges for use with the QHA of the present invention.

FIG. **18** and **19** illustrate another embodiment of a QHA of the present invention having a pivot or hinge member.

FIG. **20** illustrates a QHA of the present invention for use with a handset communications device further comprising a display.

FIGS. **21** and **22** illustrate embodiments of a mandrel for use with a QHA of the present invention.

FIGS. **23**–**25** illustrate structures associated with aligning a mandrel and a substrate of a QHA of the present invention.

DESCRIPTION OF THE INVENTION

Before describing in detail the particular antenna apparatus and a method for making the antenna according to the present invention, it should be observed that the present invention resides in a novel and non-obvious combination of hardware elements and process steps. Accordingly, these elements have been represented by conventional elements in the drawings and specification, wherein elements and method steps conventionally known in the art are described in lesser detail, and elements and steps pertinent to understanding the invention are described in greater detail.

This invention relates to an antenna responsive to a signal source supplying quadrature related currents to each of four filars, comprising a short pair of filars and a long pair of filars. The antenna further employs a simple, low cost, low loss matching element that takes advantage of the circularly polarized gain provided by the antenna filars. In one embodiment the antenna provides advantageous gain in a relatively small physical package that is near optimum in terms of gain and size when compared to other known antennas. In one application, the antenna offers desired performance features in an earth-based communications handset for communicating with a satellite.

In one embodiment, a QHA of the present invention operates over a frequency band from 2630 to 2655 MHz (i.e., a bandwidth of approximately 1%). The radiation pattern favors right hand circular polarization (RHCP). Within a solid angle of about 45 degrees from the zenith the gain is about 2.5 dBrhcpi, that is, more than 2.5 decibels relative to a right hand circularly polarized isotropic antenna. The gain at the zenith approaches 4.0 dBrhcpi. The standing wave ratio (SWR) is about 1.5:1 over the frequency range of 2630 to 2655 MHz. The QHA of the present invention, or derivative embodiments thereof, may satisfy requirements for use with an earth-based communications device for sending and/or receiving signals from a satellite, such as a GPS satellite or satellite commercial radio systems operated by XM Radio and Sirius.

FIGS. **1** and **2** illustrate a QHA **10** according to the teachings of the present invention, comprising filar windings **12**, **14**, **16** and **18** extending from a bottom region **20** to a top region **22** of the QHA **10**, which is generally in the shape of a cylinder. FIG. **1** illustrates a QHA wherein the oppositely disposed filars **12** and **16** are conductively connected by a conductive bridge **23**, and the filars **14** and **18** are conductively connected by a conductive bridge **24**. Signals propagating on the filars **12**/**16** are in phase quadrature with signals propagating on the filars **14**/**18**, to produce the desired circular signal polarization. In a preferred embodiment, the filars **12**, **14**, **16** and **18** each comprises a conductive element, such as a wire having a circular or rectangular cross-section or a conductive line or trace on a dielectric substrate.

As is known in the art, conductive bridges are employed with QHA'S having a filar length equal to an even number of quarter wavelengths at the operating frequency, but are not typically used when the filar lengths comprise an odd number of quarter wavelengths. In one embodiment, each conductive bridge **23** and **24** (also referred to as a crossbar) comprises a conductive tape strip.

In the embodiment of FIGS. **1** and **2**, the four filar conductors **12**, **14**, **16** and **18** extend in a substantially uniform helical pattern from the bottom region **20** to the top region **22** of an imaginary cylinder. In another embodiment, not illustrated, one or more of the filars is disposed about the cylinder in a zigzag or serpentine pattern from the bottom region **20** to the top region **22**.

In embodiments implementing the structure of FIGS. **1** and **2**, and for use in the band from 2630 to 2655 MHz, the cylinder diameter ranges from about 8 mm to about 10 mm. An antenna constructed according to the present invention provides a peak gain in excess of about 3.5 dBrhcpi. The maximum gain at the zenith occurs with a filar pitch angle of about 45 degrees. Increased gain within a 45 degrees solid angle from the zenith can be achieved by using a pitch angle of about 60 degrees. In another embodiment, the pitch angle is about 75 degrees, but it has been observed that the 60-degree pitch angle provides adequate gain within the 45 degrees solid angle for an intended application. Generally, lowing the pitch angle increases the gain at the zenith. An antenna constructed with a 60-degree pitch angle exhibits a shorter axial height than one with a pitch angle of 75 degrees, which may also be advantageous for some applications. Higher pitch angles tend to produce a beam peak at lower elevation angles while maintaining the peak for all azimuth angles. Also, use of a higher pitch angle tends to broaden the bandwidth and lower the SWR. An antenna constructed with a pitch angle of about 45 degrees has a narrower bandwidth and a higher SWR than a QHA with a 60 degrees pitch angle. The balanced and essentially resonant conditions to achieve satisfactory circular polarization generally suggest narrow band antennas.

A nominal length of each filar **12**, **14**, **16** and **18** is about 25 mm for an approximately quarter-wavelength antenna structure operative at about 2642.5 MHz. The nominal filar length is about 46 mm for a half-wavelength QHA. Based on these filar lengths and a pitch angle of about 60 degrees, the antenna axial height is about 18 mm for the quarter-wavelength QHA and about 39 mm for the half-wavelength QHA. In one embodiment of the quarter-wavelength QHA, the antenna comprises a diameter of about 16 mm. In a one half-wavelength embodiment, the filar structure diameter is about 8.5 mm. When completely assembled with a radio frequency connector, radome housing and a short cable disposed between the antenna and the connector, the overall dimensions are 68 mm in height and 12 mm diameter.

The half-wavelength QHA radiation pattern exhibits better forward gain and a smaller back lobe in the radiation pattern than the quarter-wavelength QHA. In other embodiments, three-quarter, five-quarter, etc. wavelength QHA'S can be utilized according to the teachings of the present invention. It is known that the higher fractional quarter wavelength embodiments provide a higher gain at the peak of the beam, i.e., a narrower radiation pattern, expanded bandwidth and a higher front hemisphere-to-back hemisphere ratio.

In a preferred embodiment of the present invention, lengths of the QHA filars are modified from the nominal length. That is, the filars **12**, **14**, **16** and **18** comprise a first pair or loop of long filars (e.g., filars **12** and **16**) and a second pair or loop of short filars (e.g., **14** and **18**), where long and short are measured with respect to the nominal length related to the antenna's resonant frequency, i.e., a nominal length of about 25 mm for a quarter-wavelength antenna operating at about 2642.5 MHz, including the length of the conductive bridge **23**/**24** and a segment of the feed structure for matching the antenna impedance to the feed structure impedance, which is described below, such that the total length circumscribes a conductive loop. The length differential between the two filar pairs maintains the phase quadrature relationship for the signals propagating on the four filars.

In a half-wavelength embodiment, the long filars each have a length of about 46 mm and the short filars each have a length of about 44.5 mm, where both lengths include the length of the conductive bridge of each filar pair and a conductive segment of the feed structure (for matching the antenna impedance to the feed structure impedance), which is described below, such that the total length circumscribes a conductive loop.

As can be seen in FIG. **1**, each of the conductive bridges **23** and **24** connects oppositely disposed filars, with an air gap **28** therebetween due to the length differential of the filars. The air gap distance thus in one embodiment controls the filar length differential. In another embodiment, the length differential is created by forming filars of unequal lengths, such as by employing different pitch angles, for the two filar pairs. Other embodiments comprising the use of other conductive structures for connecting the filar pairs are described below.

In the quarter-wavelength embodiment of the present invention for operation at about 2642.5 MHz, the long and the short filar lengths are about 23.325 mm and about 21.075 mm, respectively.

Consumer marketing considerations for emerging applications for antennas of this type, such as consumer electronic devices such as a handset as described below, tend to impose the smallest possible size on the antenna developer. The dimensions of certain of the QHA embodiments of the present invention were driven by customer requirements, and it is suggested that these dimensions are very close to the minimum size capable of providing the desired radiation pattern and bandwidth performance. It has been observed that at smaller dimensions the antenna elements tend to self absorb the radiation.

A communications handset is one application for the QHA **10**. With reference to FIGS. **1** and **2**, a radio frequency connector **32** provides an electrical connection to receiving and/or transmitting elements of the handset. In a transmit mode, a radio frequency signal is supplied to the QHA **10** from transmitting elements within the handset via the connector **32**. In a receiving mode, the radio frequency signal received by the QHA **10** is supplied to handset receiving elements via the connector **32**. As further described and illustrated below, the QHA **10** further comprises a radome, including a radome base **33** illustrated in FIGS. **1** and **2**.

An antenna of the present invention can be configured with an antenna signal feed (such as the signal feed described below) disposed at the top region **22** or the bottom region **20**. The QHA **10** exhibits different operating characteristics (including the radiation pattern) depending on whether the antenna is top fed or bottom fed. But in either case, a majority of the energy is radiated in a direction of the zenith.

If the antenna signal feed is disposed in the bottom region **20**, the QHA is operative in a forward fire axial mode with the signal feed connected directly to a signal conductor, such as a 50 ohm coaxial cable.

If the antenna signal feed is disposed proximate the top region **22**, the QHA operates in a backward fire axial mode. In one embodiment of a backward fire axial mode QHA, a transmission line is connected to a signal feed structure within the top region **22** and extends to the bottom region **20** (and in one embodiment extends below the bottom region **20**) where the transmission line is connected to a 50 ohm coaxial cable. The transmission line can operate as a quarter wavelength transmission line transformer to match the antenna impedance presented at the signal feed (also referred to as the driving point impedance) to the 50 ohm characteristic impedance of the coaxial cable. In certain applications the bottom feed structure is preferred as it eliminates the need for the transmission line (or transmission line transformer) extending between the top region **22** and the bottom region **20**.

The QHA of the present invention, like all antennas, presents a driving point impedance (at its signal feed terminal) to a transmission line feeding the antenna. For optimum power transfer, it is desired to match the antenna driving point impedance to a characteristic impedance of the transmission line, also referred to as a source or load impedance. An impedance match occurs when the resistive or real component of the antenna and the source impedance are equal, and the reactive or imaginary components are equal in magnitude and opposite in sign. Since a commonly used transmission line has an impedance of 50 ohms, it is desired to construct the QHA of the present invention with a 50 ohm impedance or an impedance that can be conveniently transformed to 50 ohms, for connection to the 50 ohm transmission line.

As described above, use of the QHA for a specific application drives the antenna's operating and physical characteristics. To achieve these characteristics, the QHA presents a relatively narrow diameter cylinder, and the relatively narrow diameter cylinder produces a driving point impedance below 50 ohms, including an inductive component. It has been found that for certain embodiments, the impedance is in a range of about 3 to 15 ohms. Similar inductance values are presented for all quarter-wavelength multiples, e.g., ¼, ½, ¾, 5/4, 7/4, etc. To achieve a 50 ohm antenna driving point impedance requires a cylinder diameter greater than is generally considered acceptable for use with the communications handset.

An impedance matching element **48** (see FIG. **3**) matches the antenna driving point impedance to the source impedance, according to the teachings of the present invention. The matching element **48** comprises an "H-shaped" conductive element **50** disposed on a dielectric substrate **52**, e.g., the conductive element **50** and the dielectric substrate **52** comprise a printed circuit board having a conductive pattern thereon. The impedance matching element **48** further comprises a signal feed terminal **54** (proximate a center of the substrate **52** orienting the various elements of the QHA symmetrically with respect to the substrate center). The center-fed impedance matching element **48** overcomes the disadvantages of the prior art baluns, providing a matching structure that can be physically integrated with the antenna radiating elements to present an integrated radiating and impedance matching structure for incorporation into a communications device, such as a handset.

In the illustrated embodiment, the QHA **10** is fed from a coaxial cable **55** comprising a center conductor **56** connected to a terminal **57**A of a capacitor **57**, and further comprising a shield **58**. An inductor **59** is connected between the center conductor **56** and the shield **58**. In a preferred embodiment, the capacitor **57** has a value of about 1.8 pF and the inductor **59** has a value of about 2.2 nH. The capacitor and inductor value are selected to provide the desired impedance match, when operating in conjunction with the structural features of the feed and the antenna elements that also affect the impedance match. The capacitor **57** and the inductor **59**, disposed as shown, form a two-element impedance match between the source impedance (of the coaxial cable **55**) and the QHA **10**. Thus, the antenna's natural driving point impedance is transformed by the capacitor and the inductor to approximately 50 ohms.

A length of the center conductor **56** should be kept short as in known by those skilled in the art. It is also known in the art that a balun can be connected proximate the signal feed terminal **54** to prevent stray radio frequency fields from generating a current in the shield **58**.

A terminal **57**B of the capacitor **57** is connected to a conductive element **60** of the impedance matching element **48** via a conductor **70**. The conductive element **60** is conductively continuous with conductive pads **61** and **62**. The shield **58** of the coaxial cable **55** is connected to conductive pads **72** and **74** via a conductive element **78**. In one embodiment, a solder filet conductively connects the shield **58** to the conductive element **78**. The filars **12** (long), **14** (short), **16** (long) and **18** (short) are disposed within openings **72**A, **74**A, **60**A and **62**A, respectively, as defined in the respective conductive pad and extend vertically from a plane of the impedance matching element **48**. A solder filet (see FIG. **11**) bridging the conductive pad and its respective filar forms the conductive connection therebetween.

To form the impedance matching element **48**, in one embodiment a conductive layer is disposed on the dielectric substrate **52**, and the conductive pads **61**, **62**, **72** and **74** and the conductive element **78** are formed by selective subtractive etching of the conductive layer.

It is noted that the filars **12** and **16** (both long) are oppositely disposed on the helix relative to a center of the substrate **52**. Similarly, the filars **14** and **18** (both short) are oppositely disposed relative to the substrate center. Thus the conductive element **60** of the impedance matching structure **48** connects the long filar **18** and the short filar **16**. Similarly, the conductive element **78** connects the long filar **12** and the short filar **14**. The conductive bridges **23** and **24** connect the filars at their upper end as described above.

The impedance matching element **48** may be disposed at the proximal end, as described, or a distal end of the QHA **10**. The physical features of the matching element **48** (including the value of the capacitor and the inductor) may change from those described above when placed at the distal end.

Exemplary current flow in the impedance matching element **48** is indicated by an arrowhead **100** from the shield **58** through the conductive element **78** to the conductive pad **72**. Current flow continues through the long filar **12**, the conductive bridge **23**, and the long filar **16** (see FIG. **1**) to the conductive pad **61**. An arrowhead **102** depicts current flow from the conductive pad **61** through the conductive element **60** and the capacitor **57** to the center conductor **56**.

Similarly, current flow is indicated by an arrowhead **104** from the shield **58**, through the conductive element **78** to the conductive pad **74**. Current flow continues through the short filar **14**, the conductive bridge **24**, and the short filar **18** (see FIG. **1**) to the conductive pad **62**. An arrowhead **106** depicts current flow from the conductive pad **62** to the center conductor **56** via the conductive element **60** and the capacitor **57**.

It is known by those skilled in the art that various radio frequency connectors can be used in lieu of the coaxial cable **55** of FIG. **3**. For example, as illustrated in the embodiments of FIGS. **1**, **2** and **5**, the connector **32** is connected to the antenna feed terminal. Terminals of the connector **32** mate with a signal cable, not shown in FIG. **3**, that comprises a signal conductor and a ground conductor. The signal conductor is operative in lieu of the center conductor **56** of the coaxial cable **55**, and the ground conductor replaces the shield **58**. Both are connected to the impedance matching element **48** in a manner similar to connection of the coaxial cable **55** as described above.

For an exemplary QHA structure having a diameter of about 8.5 mm and a pitch angle of about 60 degrees, the net reactance is about 1.6 nH (j26) at 2642.5 MHz; the resistance is about 12 ohms, for a impedance (Zdp) of about 12+j26 ohms. Note that the reactive component is about twice the series equivalent resistance. Although the actual driving point impedance depends on the antenna diameter and filar pitch angle, this tendency toward an inductive impedance of about twice the value of the resistive component may provide adequate antenna gain and SWR, while providing an acceptable solution for the quadrature relationship between the filars such that a circularly polarized signal is radiated.

It has also been found that the peak QHA gain tends to occur at a frequency slightly below a frequency where the lowest SWR is observed. Thus according to one embodiment, the QHA sacrifices some gain while achieving a satisfactory SWR. However, computer-based design iterations can be performed to adjust the filar dimensions, such as filar length (both or either of the short filar and the long filar), the filar cross-section, the cylinder radius, the filar pitch angle and the matching component values (i.e., the capacitor **57** and the inductor **59**) to achieve a greater peak gain but with a higher SWR. Once these filar dimensions and match component values are determined, an antenna constructed based thereon presents reasonable process tolerances to achieve the desired performance.

Design of a QHA according to the present invention considers the relationship between the various antenna physical parameters and the desired operating characteristics. According to one embodiment as described above, the antenna physical parameters are optimized to present an antenna driving point impedance (i.e., a series equivalent impedance) having a real part less than 50 ohms and a positive reactive part. In various embodiments of the invention the remaining reactive component due to the inductance of the conductive structures in the impedance matching element **48** is proportional to the length of those structures. Generally, the reactive component is about twice the resistive component or is in the range of 20 to 40 ohms reactive. According to investigations performed by the inventors, it appears that the QHA exhibits desired, gain, bandwidth, etc. parameters when this relationship between the real and reactive impedance components is presented.

According to one application, it is desired for the QHA to have a relatively small cylindrical diameter for use with the handset communications device. The antenna characteristic impedance is directly related to the antenna diameter, i.e., a smaller diameter lowers the characteristic impedance. Reducing the diameter also lowers the resonant frequency and reduces the bandwidth. A small diameter QHA with equal length first and second filar pairs tends to present a somewhat wider bandwidth and a somewhat higher peak gain, when compared to an embodiment with unequal length filar pairs. However, an elaborate quadrature feed network, such as the branch line hybrid couple described above in the Background section, is required to drive a QHA with equal length filars. By contrast, according to the present invention adequate bandwidth and gain can be achieved by utilizing different length filar pairs operating with a quadrature feed network for impedance matching, such as the impedance matching elements **48** (described above in conjunction with FIG. **3**) and **110** (described below in conjunction with FIG. **4**).

The capacitor **57** and the inductor **59** of the impedance matching structure **48** of FIG. **3** are selected to provide an impedance match between the driving point impedance of the QHA and the 50 ohm characteristic impedance of the coaxial cable **55** connected to the antenna signal feed terminal **54**. As is known in the art, in another embodiment the lumped inductor and capacitor can be replaced by distributed components for performing the impedance matching function, such as a capacitor formed by interdigital conductive traces on the substrate **52** and an inductor formed by a conductive trace in the form of one or more conductive loops or a linear conductive segment. In a further embodiment, the source characteristic impedance is other than 50 ohms, and thus the capacitor and inductor are selected to match to this impedance.

According to another embodiment, a balanced transmission line, selected from one of the various types known in the art, is used instead of the coaxial cable **55**. Each conductor of the balanced transmission line is attached to a conductive pad, with the conductive pads disposed on opposing surfaces of a printed circuit board, such as the substrate **52** of FIG. **3**. Each pad is further connected to the signal feed terminal **54** of FIG. **3** using conventional connection techniques.

As is recognized by those skilled in the art, different dimensions for the components of the QHA **10** (e.g., a different diameter, different filar lengths or a different filar pitch angle) can be used in another embodiment. These parameters may change the differential length between the first and the second filar pairs and/or the antenna load impedance, which in turn changes the value of the inductor and/or the capacitor for matching the antenna impedance to the source impedance. In one embodiment, the impedance match may require only a single component (either an inductor or a capacitor). However, as discussed above, to optimize the antenna operating characteristics, it may be preferable for the driving point impedance to include a reactive component.

To achieve optimum bandwidth, gain and quadrature signal distribution (which is required for a circularly polarized signal) it is desired that the long and the short filar pairs have an approximately equivalent diameter (or an equivalent cross-section for filars having a quadrilateral cross-section (i.e., length and width) such as filars comprising a conductive trace on a dielectric substrate). It may be possible, however, to accommodate slightly divergent diameters without dramatically affecting antenna performance. Use of same diameter conductors also simplifies the physical filar structure and maintains antenna symmetry.

In one embodiment, the QHA diameter is about 8.5 mm, and thus the antenna circumference is about 25 mm. It is desired to use as wide a conductor as practical to lower the conductor resistance (i.e., reduce ohmic losses), which correspondingly tends (to a point) to broaden the antenna bandwidth. It is also recognized that the filars must be separated by a sufficient distance to reduce filar-to-filar coupling and dielectric loading. In one embodiment, the filar diameter is determined by dividing the antenna circumference by eight and rounding to a convenient integer value. Thus, a 25 mm circumference yields a filar diameter of about 3 mm. According to an embodiment wherein a filar comprises a flat conductor, a half conductor, half dielectric relationship is used to establish a conductor width. Several embodiments of the antenna according to the present invention have favored the above conductor-to-insulator ratio, although it is recognized that other embodiments may favor other ratios. As is known by those skilled in the art, in performing analyses of such QHA'S, a flat conductor can be represented by a round conductor where a diameter of the round conductor is one-half the flat conductor width.

In one embodiment presented above, the driving point impedance of 15+30j is transformed by the impedance matching element **48** (specifically the capacitor **57** and the inductor **59**) to 50 ohms for matching the characteristic impedance of the coaxial cable **55**. According to another embodiment, such as a quarter wave version of a QHA described below according to the teachings of the present invention, a capacitor and/or an inductor transform the driving point impedance of 3+6j to about 12.5 ohms, and a quarter wavelength transformer transforms the 12.5 ohm impedance to 50 ohms. A quarter wavelength transmission line having a 25 ohm characteristic impedance (Z_0) transforms the 12.5 ohms impedance to 50 ohms according to the equation, Z_0=sqrt [(driving point impedance)*(source impedance)].

FIG. **4** illustrates an embodiment of an impedance matching element **110** including a quarter wavelength transmission line transformer **112** connected at the signal feed terminal **54** to match a 12.5 ohms impedance to 50 ohms. The transmission line transformer **112** comprises a conductor **118** connected to an arm **120** of the conductive element **50**, and a conductor **124** connected to an arm **128**.

As can be appreciated by those skilled in the art, in an embodiment where the antenna's physical parameters create a purely resistive driving point impedance of about 12.5 ohms, the impedance matching element **110** is sufficient to transform the driving point impedance to 50 ohms. The impedance matching element **48** is not required.

A radome is advantageous to avoid antenna damage during user handling of the communications device to which the antenna is connected. Radome material, thickness and shape is chosen to minimize effect on the antenna's receiving and transmitting properties, i.e., to present relatively low loss over the antenna's operating frequency range. The dielectric loading effect of the radome can be considered in designing the QHA to achieve operation at the desired resonant frequency and desired bandwidth. A suitable radome **130** for the QHA **10** is illustrated in FIG. **5**. As can be seen, the radome **130** mates with the radome base components **33**A and **33**B that enclose the lower region **20** of the QHA **10**.

Another embodiment according to the teachings of the present invention is represented by a QHA **140** illustrated in FIG. **6**, comprising a conductor **142**, preferably a coaxial cable comprising an inner conductor and an outer shield, extending between the connector **32** and the impedance matching element **48** within the bottom region **20** of the QHA **140**. Typically, due to a length of the conductor **142**, the impedance matching element sees a different impedance with the conductor **142** in place than when the QHA **140** is connected directly to the connector **32**, such as shown in FIG. **5**. Thus the impedance matching components of the impedance matching element **48** must be modified to provide an appropriate impedance match for the QHA **140**. In a preferred embodiment the conductor **142** comprises a flexible conductive material that can absorb mechanical shock and vibrations caused by dropping or striking the QHA **140** against a rigid object, reducing the likelihood of damage to the QHA **140**. The length of the conductor **142** provides a physical separation between the connector **32** and the QHA **140** in a handset mounting application where such a separation is advantageous.

In an embodiment of FIG. **7**, a QHA **144** further comprises an over-molded deformable (e.g., semi-plastic) member **146** enclosing the conductor **142** and in one embodiment affixed to the impedance matching element **48** and to a surface **32**A (see FIG. **6**) of the connector **32**. The member **146** provides shock absorbing capability when the antenna is dropped. The QHA **144** further comprises the radome or cover **130**. The over-molded member **146** can also be used in conjunction with the embodiment of FIG. **6**, wherein a portion of the conductor **142** is enclosed by the over-molded member **146**.

FIG. **8** illustrates yet another embodiment of a QHA **150** comprising a conductor extending between the connector **32** and the impedance matching element **48** enclosed within a sleeve **152**.

To ensure desired performance parameters for the QHA it is preferable to maintain the antenna dimensions and limit flexing of the filars **12**, **14**, **16** and **18** during operation. To provide consistent antenna performance, it is also desired to control a shape and a mass of solder filets **156** (see FIG. **9**) that conductively connect each filar to its respective mounting pad **72**, **74**, **60** and **62** of the impedance matching element **48** (see FIG. **3**). It is known that varying a shape, mass and/or size of one or more of the solder filets **156** can change the current path length of the QHA filars, and thus can alter various performance parameters, including the antenna's resonant frequency. In certain manufacturing process for producing the QHA **10**, the solder filets **156** are formed by a hand soldering operation leading to potential performance variability.

To overcome the filar flexing, in one assembly process the substrate **160** (see FIG. **10**) comprising filars **162**, is wound about a tubular mandrel **163** (see FIG. **11**) and retained in the cylindrical shape by the mandrel **163**, i.e., the mandrel remains in place after fabrication of the QHA **10**. Various known adhesives are suitable for attaching the substrate **160** to the mandrel **163**. A material of the mandrel **163** is chosen to exhibit low loss at the antenna's operational frequencies, while providing mounting integrity and stability for the substrate **160**.

The mandrel **163** dielectrically loads the QHA **10**, which tends to lower the antenna resonant frequency. Thus the dielectric loading imposed by the mandrel **163** should be considered when determining the antenna dimensions to overcome the loading effects. Other antenna embodiments in which the dielectric loading effect is reduced are described below.

Each filar **162** further comprises a finger segment **164**A extending beyond a bottom edge **160**A of the substrate **160** and a finger segment **164**B extending beyond a top edge **160**B of the substrate **160** (see FIGS. **10** and **11**). The finger segments **164**B are illustrated as having unequal lengths to form the unequal length filars of the QHA as described above. In another embodiment not illustrated, the finger segments **164**B are of substantially equal length and the unequal total filar conductive length is a result of the differential electrical path length of the conductive bridges **23** and **24** or other conductive bridge or crossbar embodiments described below.

As can be seen in FIG. **12**, each finger segment **164**A wraps about a tab **165** in the mandrel **163** when the substrate **160** is disposed about the mandrel **163**. According to this embodiment, an impedance matching element **166**, similar in functionality to the impedance matching element **48**, comprises a disk-like structure with the impedance matching components (as further described in conjunction with FIG. **3**) mounted on an upper surface that is hidden from view in FIG. **12**, and conductive regions **170**, each in conductive communication with the conductive elements on the upper surface, wherein these conductive elements provide the functionality of the conductive pads **61**, **62**, **72** and **74** and the conductive elements **60** and **78** of the impedance matching element **48** of FIG. **3**. Preferably, the conductive regions **170** are formed co-extensive with the conductive pads and elements according to known printed circuit board subtractive conductor etching techniques. The impedance matching element **166** further comprises a feed terminal **171** for connection to the conductor **142** of FIG. **6**, for example.

The impedance matching element **166** is captured within an opening **172** at a lower end of the mandrel **163**. Each finger segment **164**A (and corresponding tab **165**) is thereby urged into conductive communication with one of the conductive regions **170** to electrically connect the filars **162** to the impedance matching components mounted on the upper surface of the impedance matching element **166**.

Oppositely-disposed capture tabs **173** (a single capture tab **173** may suffice in one embodiment) extending from a bottom edge **174** of the mandrel **163**, capture and apply an upwardly directed force to a lower surface **175** of the impedance matching element **166**, urging the element **166** against the bottom edge **174**, thereby retaining the element **166** within the opening **172** of the mandrel **163**. See also FIGS. **13** and **14**. To install the impedance matching element **166**, the cylindrical shape of the mandrel **163** is slightly distorted by the application of suitably directed forces so as to permit insertion of the element **166** against the bottom edge **174**. Upon removal of the distorting forces, the mandrel **163** returns to its normal shape and the impedance matching element is captured as described. Although the impedance matching element **163** is illustrated in the Figures. as having a particular shape including a plurality of notches formed therein, those skilled in the art recognize that other shapes non-illustrated may be suitable.

In another embodiment, the flexible film is replaced by a rigid cylindrical structure on which conductive strips forming the helical traces are disposed, for example, by printing conductive material on outer surface of the cylindrical piece or by employing a subtractive etching process to remove certain regions from a conductive sheet formed on the outer surface, such that the remaining conductive regions form the helical traces.

In yet another embodiment, the conductive bridges or crossbars **23** and **24** are replaced with a generally circular substrate (or printed circuit board) **180**, having a thickness d (see FIG. **15**) with conductive crossbar strips **182** and **184** disposed on opposing surfaces **180**A and **180**B thereof In one embodiment, the distance d is about 1 mm. Each of the filars **12**, **14**, **16** and **18** comprises the finger segment **164**B (see FIG. **10**) at the crossbar end thereof. Each finger segment **164**B extends into an upper opening **190** of the mandrel **163**. The crossbars **182** and **184** are electrically connected to one of the filars **12**, **14**, **16** and **18** via conductive regions **185**A–**185**D (only one of which is illustrated in FIG. **15**) spaced about a circumferential edge of the substrate **180**, such that when the substrate **180** is frictionally engaged within the upper opening **190**, the conductive regions **185**A–**185**D electrically connect and physically mate with the filar finger segments **164**B. In one embodiment the conductive regions **185**A–**185**D comprises gold-plated conductive material to reduce oxidation at the surface thereof

Use of the substrate **180** provides additional dimensional stability to the QHA **10** by controlling the distance between the filars at the upper end of the antenna, according to the dimensions of the substrate **180**. Dimensional changes at the upper end of the antenna can lead to frequency detuning and/or gain reduction. As discussed above, the distance d is related to the length differential between the long and the short filars.

FIGS. **16** and **17** illustrate another embodiment of a circular substrate **200** supporting the conductive crossbars **182** (on an upper surface of the substrate **200**) and **184** (not visible in FIGS. **16** and **17**). The filar finger segments **164**B are wrapped vertically about tabs **210**A and tabs **210**B, the tabs **210**B extending farther from an upper edge **211** of the mandrel **163** than the tabs **210**A. A terminal end of each finger segment **164**B is disposed over an interior-facing surface of each tab **210**A and **210**B.

Capture tabs **216** and **217** extend from the upper edge **211**, wherein the capture tab **216** further comprises a projection **218** extending inwardly from an interior-facing surface of the tab **216**. The capture tabs **216** and **218** and the projection **218** cooperate to retain the substrate **200** against the upper edge **211** and properly aligned with the outer surface of the mandrel **163**. In another embodiment, the capture tab **217** also comprises a projection **218**.

The QHA embodiments of the present invention can be tuned by using electrically differentiated embodiments of the substrate **180** and/or of the impedance matching element **166**. For example, due to coupling between the crossbars **182** and **184**, the QHA can be tuned by varying the height d of the substrate **180**, which modifies the parasitic capacitance and changes the resonant frequency of the QHA. The QHA can also be tuned by changing the dielectric constant of the substrate **180** or the impedance matching element **166**, i.e., substituting a material having a different dielectric constant.

To expedite the antenna manufacturing process, a number of substrates **182** of varying height are manufactured. As each antenna is tested following manufacture, a substrate of the appropriate height is selected to tune the antenna to the desired resonant frequency.

In another embodiment, the relative orientation of the crossbars **182** and **184** is altered to tune the antenna. In FIG. **15** the crossbars **182** and **184** are separated by an angle α of about 70–80 degrees. Changing this orientation such that the angle α is less than 70–80 degrees modifies coupling between the crossbars **182** and **184** to effect antenna tuning.

In another embodiment illustrated in FIGS. **18** and **19**, an antenna assembly **300** comprises a generally cylindrical enclosing member **302** enclosing a QHA of the present invention. An enclosing member **304** encloses the impedance matching element and certain components associated with the connector. The enclosing members **302** and **304** are pivotably joined by a hinge structure **310** as illustrated.

In FIG. **18** the enclosing members **302** and **304** are substantially linearly oriented.

As illustrated in FIG. **19**, the hinge structure **310** permits pivoting of the antenna **314** into a perpendicular orientation with respect to the connector **32**. Depending on the characteristics of the hinge structure **310**, an orientation greater than 90 degrees may also be permitted. Arrowheads **315** in FIG. **19** indicate a range of permitted angular orientations between the connector **32** and the antenna **314** as permitted by the hinge structure **310**. An arrowhead **316** in FIG. **19** indicates that the connector **32**, and thus the antenna assembly **300**, can be rotated through 360 degrees when inserted into a handset or other communications device. A combination of the rotating feature and the pivoting feature of the present invention offers a nearly limitless range of positions for the antenna assembly **300** relative to the communications device to which it is connected.

FIG. **20** depicts a quarter-wavelength quadrifilar helical antenna **350** connected to a handset communications device **352** via a conductor **354**. The handset device **352** further comprises a fixed or base member **352**A and a movable member **352**B, the latter having a first position in a parallel back-to-back orientation relative to the fixed member **352**A and a second position in a perpendicular orientation relative to the fixed member **352**A. The second position, as illustrated in FIG. **20**, reveals a display **356** suitably oriented for viewing multimedia files received by the handset **352**. A length of the conductor **354** is determined to accommodate the second position of the rotatable member **352**B.

As expected, the quarter-wavelength QHA **350** does not provide the same operating characteristics as the half wavelength QHA **10** described above. In particular, the gain of the antenna **350** is reduced relative to the gain of the QHA **10**. In one embodiment, the gain reduction is about 2 dBic.

As described above, when an quadrifilar helical antenna of the present invention is operated with a mandrel for dimensional stability, the mandrel dielectrically loads the antenna and thereby changes its performance characteristics. In one embodiment, a plurality of openings **400** are formed in a mandrel **402** as illustrated in FIG. **21** to reduce the mandrel dielectric loading. In another embodiment, a mandrel **410** (see FIG. **22**) comprises a plurality of dielectric strips **412** affixed to or formed concurrently with a cylindrical element **414**. When the filar substrate **160** of FIG. **10** is disposed about the mandrel **410**, an open region **412**A between adjacent strips **412** presents an air dielectric to the QHA **10**, and thus lowers the dielectric loading of the mandrel **410** on the QHA **10**.

In yet another embodiment, a mandrel material comprises a dielectric and the conductive filars **12**, **14**, **16** and **18** are formed directly thereon. For example, the conductive filars **12**, **14**, **16** and **18** are formed from conductive material comprising an adhesive rear surface for adhesive attachment to the mandrel. In another embodiment, the filars **12**, **14**, **16** and **18** are formed of conductive ink applied directly to the mandrel by known printing techniques.

To ensure proper alignment between the mandrel **163** and the substrate **160** (see FIG. **10**), according to one embodiment, the mandrel comprises projecting bosses **450** on an outside surface thereof, as illustrated in FIG. **23**. The substrate **160** defines corresponding holes or openings **452** as illustrated in FIG. **24**. When the substrate **160** is disposed about the mandrel **160**, the bosses **450** protrude through the openings **452** to ensure proper alignment between the substrate **160** and the mandrel **163**. See FIG. **25**.

While the present invention has been described with reference to preferred embodiments, it will be understood by those skilled in the art that various changes may be made and equivalent elements may be substituted for the elements thereof without departing from the scope of the present invention. The scope of the present invention further includes any combination of the elements from the various embodiments set forth herein. In addition, modifications may be made to adapt a particular situation to the teachings of the present invention without departing from its essential scope. Therefore, it is intended that the invention not be limited to the particular embodiments disclosed, but that the invention will include all embodiments falling within the scope of the appended claims.

What is claimed is:

1. A quadrifilar helical antenna, comprising:

a substantially cylindrical substrate defining axially spaced-apart base and end regions;

first and second helical filar segments each having a first length and each defining a first end proximate the base region, the first and the second filar segments extending toward the end region;

second and third helical filar segments each having a second length different than the first length and each defining a first end proximate the base region, the third and the fourth filar segments extending toward the end region; and

an impedance matching element disposed proximate the base region and comprising legs extending from a center region, each leg conductively connected to the first end of one of the first, the second, the third and the fourth filar segments, the impedance matching element further comprising a feed terminal in the center region, the impedance matching element for matching an antenna impedance to a source impedance.

2. The antenna of claim **1** further comprising a cylindrical dielectric structure, wherein the substrate comprises a flexible dielectric film disposed about the cylindrical structure, and wherein each one of the first, the second, the third and the fourth filar segments comprises a finger segment extending beyond an edge of the dielectric film such that the finger segments extend beyond a lower edge of the cylindrical structure, and wherein the impedance matching element comprises first, second, third and fourth conductive pads disposed at a terminal end of a respective first, second, third and fourth legs extending from the center region and in electrical communication with impedance matching components disposed on the impedance matching element, and wherein the impedance matching element is mated with the cylindrical structure such that each one of the first, the second, the third and the fourth conductive pads is in conductive communication with the finger segment of one of the first, the second, the third and the fourth filar segments.

3. The antenna of claim **2** wherein a resonant frequency of the antenna is responsive to a thickness of the disk-like structure.

4. The antenna of claim **2** wherein a resonant frequency of the antenna is responsive to a dielectric constant of a material of the disk-like structure.

5. The antenna of claim **2** wherein a material of the first, the second, the third and the fourth conductive pads comprises conductive material having a gold-plated surface.

6. The antenna of claim **2** further comprising finger tabs extending from the lower edge of the cylindrical structure, wherein each one of the finger segments extends over one of the finger tabs, and wherein each one of the finger tabs is received within a corresponding notch defined in the disk-like structure, and wherein each one of the first, the second, the third and the fourth conductive pads of the disk-like structure is urged against one of the finger tabs with the finger segment extending thereover to facilitate conductive communication between each one of the finger segments and one of the first, the second, the third and the fourth conductive pads.

7. The antenna of claim **6** further comprising a projection extending from the cylindrical structure in a direction toward an interior of the cylindrical structure, wherein the projection contacts a bottom surface of the disk-like structure to urge the disk-like structure against the lower edge of the cylindrical structure.

8. The antenna of claim **1** wherein the substrate comprises a dielectric film, and wherein the first, second, third and fourth filar segments are disposed on the dielectric film, and wherein each one of the first, the second, the third and the fourth filar segments comprises a finger segment extending beyond an edge of the dielectric film, and wherein the first and the second filar segments are serially connected through a first conductive element electrically connected between the finger segment of the first filar segment and the finger segment of the second filar segment, and wherein the third and the fourth filar segments are serially connected through a second conductive element electrically connected between the finger segment of the third filar segment and the finger segment of the fourth filar segment.

9. The antenna of claim **8** wherein a length of the finger segment of the first and the second filar segments is substantially identical and different from a length of the finger segment of the third and the fourth filar segments, wherein the length of the finger segment of the third and the fourth filar segments is substantially identical.

10. The antenna of claim **8** wherein the first and the second conductive elements are disposed on a crossbar structure in an insulative relation.

11. The antenna of claim **10** wherein the first and the second conductive elements each comprise a conductive strip disposed in a stacked relation within or on a surface of the crossbar structure, and wherein a resonant frequency of the antenna is responsive to an angle formed between the first and the second conductive strips.

12. The antenna of **10** further comprising a cylindrical dielectric structure, wherein the substrate comprises a flexible dielectric film disposed around the cylindrical structure, and wherein the crossbar structure comprises a disk-like shape having a first, a second, a third and a fourth conductive pad disposed about a circumferential surface thereof, and wherein the first and the second conductive elements are disposed on a surface of or within the crossbar structure, and wherein the first and the second conductive pads are electrically connected by the first conductive element and the third and the fourth conductive pads are electrically connected by the second conductive element, and wherein the crossbar structure is mated with the cylindrical structure such that the first and the second conductive pads are in conductive communication with the finger segment of the first filar segment and the finger segment of the second filar segment, respectively, and wherein the third and the fourth conductive pads are in conductive communication with the finger segment of the third filar segment and the finger segment of the fourth filar segment, respectively.

13. The antenna of claim **12** wherein the cylindrical structure further comprises a projection extending in a direction toward an interior of the cylindrical structure, wherein the projection is in contact with a bottom surface of the crossbar structure to urge the crossbar structure against the lower edge of the cylindrical structure.

14. The antenna of claim **12** wherein a resonant frequency of the antenna is responsive to a thickness of the crossbar structure.

15. The antenna of claim **12** wherein a resonant frequency of the antenna is responsive to a dielectric constant of a material of the crossbar structure.

16. The antenna of claim **12** wherein a material of the first, the second, the third and the fourth conductive pads comprises conductive material having a gold-plated surface.

17. The antenna of claim **12** further comprising finger tabs extending from the lower edge of the cylindrical structure, wherein each one of the finger segments warps about one of the finger tabs, and wherein each one of the finger tabs is received within a corresponding notch defined in the crossbar structure, and wherein each one of the first, the second, the third and the fourth conductive pads of the crossbar structure is urged against one of the finger tabs with the finger segment wrapped thereabout to facilitate conductive communication between each finger segment and one of the first, the second, the third and the fourth conductive pads.

18. The antenna of claim **1** further comprising a cylindrical dielectric structure, wherein the substrate comprises a flexible dielectric film disposed around the cylindrical structure, and wherein the cylindrical structure defines a plurality of openings therein.

19. The antenna of claim **1** further comprising a cylindrical dielectric structure, wherein the substrate comprises a flexible dielectric film, and wherein a plurality of ribs are disposed on an external surface of the cylindrical structure, and wherein the flexible dielectric film is disposed around the cylindrical structure adjacent the plurality of axial ribs.

20. The antenna of claim **1** further comprising a cylindrical dielectric structure, wherein the substrate comprises a flexible dielectric film, and wherein a material having a lower dielectric constant than a material of the cylindrical structure is interposed between the cylindrical structure and the dielectric film.

21. The antenna of claim **1** further comprising a cylindrical dielectric structure, wherein the substrate comprises a flexible dielectric film, and wherein the flexible dielectric film defines a plurality of openings therein and an external surface of the cylindrical structure comprises a plurality of corresponding protrusions for receiving one of the plurality of openings.

22. The antenna of claim **1** further comprising a connector in electrical communication with the center region of the impedance matching element, wherein an open electrical terminal of the connector is adapted for connection to a communications device operative with the quadrifilar helical antenna.

23. The antenna of claim **22** wherein the connector is disposed underlying and spaced apart from the impedance matching element, and wherein a length of a conductor electrically connects the connector and the impedance matching element.

24. The antenna of claim **23** wherein the conductor comprises a coaxial cable.

25. The antenna of claim **23** the conductor comprises a shock-absorbing length of conductive material.

26. The antenna of claim **23** wherein the conductor is substantially surrounded by a flexible sleeve.

27. The antenna of claim **23** wherein the conductor is substantially surrounded by an over-molded element extending between the impedance matching element and the connector.

28. The antenna of claim **23** wherein a portion of the length of the conductor is substantially surrounded by an over-molded element.

29. The antenna of claim **1** wherein the first, second, third and fourth filar segments are substantially surrounded by a cover, the antenna further comprising a connector in electrical communication with and physically underlying the impedance matching element, wherein an open electrical terminal of the connector is adapted for connection to a communications device operative with the antenna, and wherein the connector is pivotally joined to the cover to permit adjustment of an angle formed between the cover and the connector.

30. The antenna of claim **29** wherein the open electrical terminal forms a rotatable joint with the communications device permitting rotation of the antenna with respect to the communications device.

31. The quadrifilar helical antenna of claim **1** wherein the first length is longer than a resonant length at a resonant frequency and the second length is shorter than the resonant length at the resonant frequency.

32. The quadrifilar helical antenna of claim **1** wherein the impedance matching element creates a quadrature phase relationship for signals propagating on the first, second, third and fourth filar segments.

33. A handset communications device comprising:

a base;

a cover movably engaged with the base for manipulation into different orientations with respect to the base;

a quadrifilar helical antenna disposed in the base, the antenna comprising:

  a substantially cylindrical substrate;

  a first, a second, a third and a fourth helical filar disposed on the substrate, wherein at least two of the first, the second, the third and the fourth filars have a different length;

  an impedance matching element conductively connected to the first, second, third and fourth filars for matching an antenna impedance to a source impedance; and

  a connector disposed between the impedance matching element and the base.

34. The antenna of claim **33** further comprising a conductive element extending between and electrically connecting the connector and the impedance matching element, wherein a length of the conductive element is determined to accommodate the different orientations of the cover with respect to the base.

35. The antenna of claim **33** further comprising a cover substantially surrounding the cylindrical substrate, wherein the connector forms a pivoting joint with the cover to adjust an angle formed between the cover and the connector.

36. The antenna of claim **33** wherein the connector forms a rotatable joint with the base to permit rotation of the antenna relative to the base.

37. The quadrifilar helical antenna of claim **33** further comprising a first conductive element for forming a first helical conductor by serially connecting the first and the second helical filars and a second conductive element for forming a second helical conductor by serially connecting the third and the fourth helical filars, and wherein a length of the first helical conductor is different than a length of the second helical conductor.

* * * * *